# Microwave: A novel approach to tackle herbicide resistance in no-till farming systems

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**Summary** Herbicide resistance has constrained sustainable crop productivity. Consequently, interest in chemical-free weed management has increased. We examined the effect of pre-sowing microwave (MW) soil heating to debilitate the weed seedbanks of confirmed herbicide-resistant weeds of the Australian rice and wheat production systems. The MW energy was projected through a horn antenna with aperture dimensions of 5.5 × 11 cm into the top soil (0–6 cm) horizon. An energy range of 500–700 J cm$^{-2}$ gave a temperature gradient of 80–90°C. This temperature achieved approximately 70–80% reduction in weed establishment in both rice and wheat crops. Therefore, in the case of rice, a 34% increase in the grain yield (9.0 t ha$^{-1}$) was achieved compared to the non-MW treated scenario (6.7 t ha$^{-1}$). Similarly, a substantial increase in wheat grain yield of 39.2% was achieved through MW energy application (7.8 t ha$^{-1}$), compared to non-MW treated plots (5.6 t ha$^{-1}$). In summary, investment in this new technology can effectively minimise the weed pressure and promote sustainable crop production.

**Keywords** Microwave soil heating, seedbank, wheat, rice.

## INTRODUCTION

Globally, 471 unique cases of herbicide resistance (species × site of action) have been documented in 86 crops, with 250 weed species being resistant to 160 herbicides (Heap 2016). This is a significant threat to the sustainable productivity of agricultural commodities in industrialised countries. Globally, 51 weed species are resistant to various chemical herbicides in rice crops and 73 weed resistance cases have been reported in wheat crops (Heap 2016). In Australia, no-till farming practices have increased the use of chemicals for weed management, which has ultimately shifted the weed flora to evolve herbicide resistance. In no-till farming system, early weed seed shedding favours weed seedbank accumulation in top soil layers. Controlling seed bank viability promotes long-term weed suppression in agriculture systems (Burnside *et al.* 1986). Physical methods of weed control can potentially manage herbicide resistant weed populations. Among those physical control methods, MW soil treatment has recently emerged as an alternative to tackle herbicides-resistant weeds in the Australian agricultural system (Brodie *et al*. 2017, Khan *et al*. 2017). It has been reported that pre-emergence MW irradiation of soil can potentially minimise weed establishment (Nelson 1996, Sartorato *et al*. 2006, Brodie *et al*. 2017). It can also destroy weed plants' reproductive parts and their seeds that are covered up by soil to a depth of several centimetres (Brodie *et al*. 2007). Considering all these findings, therefore, the efficacy of microwave for weed control in crops, under field conditions, is not well studied. Hence, the objective of this study was to evaluate the effect of microwave soil treatment for weed management in the Australian dryland wheat and rice farming systems, under field conditions.

## MATERIALS AND METHODS

A rice crop field experiment was conducted between October 2015 and April 2016 at Dookie Campus, The University of Melbourne, Victoria, Australia. An area of 73.5 m$^2$ was excavated and manually levelled into a turkey-nest pond so the area could be flood irrigated to grow rice. The individual experimental plot sizes were 2.0 × 2.0 m, which were arranged in a randomised complete block design with five replications, and with a 0.5 m untreated buffer zone between each experimental plot. The experiment consists of two treatments: an untreated control ($MW_0$ = 0 sec) and microwave treated ($MW_1$ = 120 sec). A MW prototype was developed for soil irradiation. It was based on the magnetron of a commercial microwave oven (EMS8586V; Sanyo; Tokyo, Japan) operating at 600 W with a frequency of 2.45 GHz, which was assembled with a rectangular waveguide of 86 × 43 mm channelling the MW energy into a pyramidal horn antenna with aperture dimensions of 110 × 55 mm. After microwave soil treatment, the plots remained undisturbed until the next day. The pre-germinated seeds of the rice variety Opus were broadcast at a seeding rate of 125 kg ha$^{-1}$. A similar experimental protocol was adapted for a dryland wheat crop experiment, under field conditions between May–December 2016. The number of tillers, fresh biomass, and dry biomass, for both rice and wheat crops, were measured for randomly selected 0.25 $m^2$ quadrats, drawn from each plot, for early growth assessment in response to MW soil heating, and weights were converted to tonnes per hectare. At physiological maturity, the crops were manually harvested from whole plots for yield assessment.

After harvesting, the crop biomass was dried in an air oven (TR1050 27124, Nabertherm, Lilienthal, Germany) for 24 h at 65°C, and final crop yield was converted to tonnes per hectare. Weed density and biomass accumulation were assessed from whole plot areas (2.6 $m^2$) at maximum tillering stage, and dry biomass of weeds was assessed at crop harvest.

Furthermore, two further rice field trials were conducted from October 2016 to April 2017 in a randomised complete block design with five replications at two different locations – Dookie, Victoria and Jerilderie, New South Wales. A MW weed killer has been designed to eradicate the weeds between crop rows and for pre-emergence soil treatment. It has four independently controlled, 2 kW microwave generators operating at 2.45 GHz. The trailer is powered by two onboard 7 kVA, 3-phase electrical generators (Brodie *et al.* 2017).

The MW energy is channeled to the ground via waveguides (390 mm long) and horn antennae with aperture dimensions of 55 × 110 mm. However, in this study, treatment of up to 60 sec duration occurs while the trailer was stationary. The selection of 60 sec was based on the results of a previous field trial, where a treatment duration of 120 sec with MW power source of 0.7 kW was used (Khan *et al*. 2017). The trailer was then moved forward by about 8 to 10 cm and treatment was done again in the next small section of soil. At both locations, after MW soil treatments, the plots remained undisturbed for a few hours, after which the rice variety YRM70 was sown with a small seed plotter at the seed rate of 80 kg $ha^{-1}$ with a row-to-row spacing of 25 cm. All the agronomic practices were maintained, and final data were collected at crop harvesting.

For all the trials, the obtained data were subjected to normality assessment and single factor Analysis of Variance was performed using MATLAB® R2015b (The Mathworks Inc., Natick Massachusetts, USA) to determine statistically significant means, and a least significant difference (LSD) test was used to compare the treatment means at a 5% probability level.

RESULTS

Pre-emergence MW weed management relies on the temperature distribution in the soil. The applied MW energy density in the treated plots, accounting for MW energy reflections from the soil in the absence of using any wave-guide tuning, was approximately 560 J $cm^{-2}$. This increased the temperature profile of top soil (0–6 cm) to approximately 75 ± 5°C, evidenced through thermal images (Figure 1), and a thermometer.

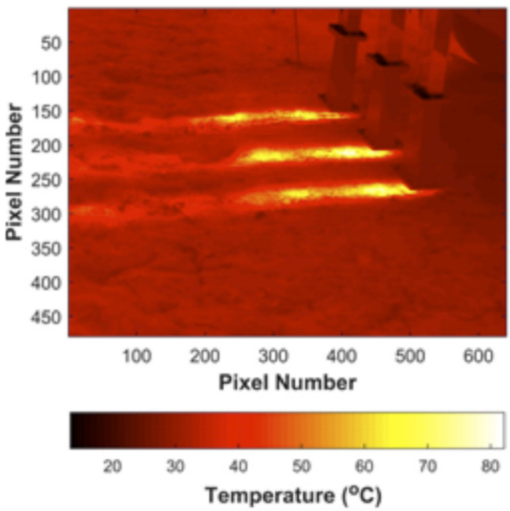


**Figure 1.** Infrared thermal image of microwave treated plot for reducing weed seedbank viability.

In the case of the first rice crop, the MW soil treatment significantly (P<0.001, Figure 2) reduced the weed density (17.6 plants $plot^{-1}$), weed fresh biomass (156.4 g $plot^{-1}$) and weed dry biomass accumulation (21.6 g $plot^{-1}$) compared to the untreated control plots; 94.8 plants $plot^{-1}$, 612.8 g $plot^{-1}$ and 122.6 g $plot^{-1}$, respectively. Overall, the pre-emergence MW irradiation of soil gave a 70–80% reduction in weed establishment.

Similarly, in the dryland wheat field experiment, the pre-emergence application of MW energy, fed through a horn antenna into the soil, significantly (P<0.001, Figure 2) reduced weed density, weed fresh weight, and dry weight in the wheat crop (Table 2) compared to the untreated control plots. The overall reductions in weed density, weed fresh weight, and dry weight, achieved with MW application in the dryland wheat crop, were 62.9%, 89%, and 90%, respectively.

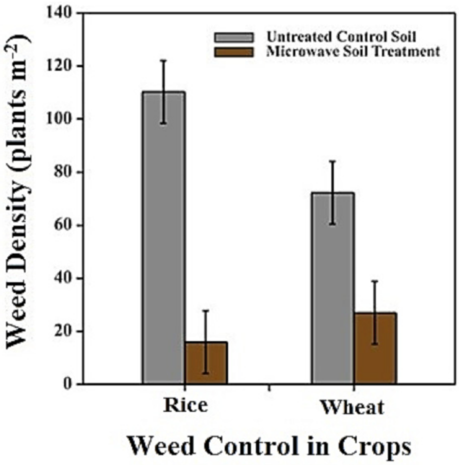


**Figure 2.** Effect of pre-cropping microwave soil heating on the weed density of rice and wheat crop measured at crop harvesting at Dookie, Victoria.

During the first year's rice experiment, the projection of MW energy into soil, for pre-emergence weed management, significantly ($P<0.001$, Table 1) increased the tiller density (419 $m^{-2}$) and grain yield (9.0 t $ha^{-1}$) of rice, compared to the untreated control (292 $m^{-2}$, and 6.7 t $ha^{-1}$, respectively). A significant difference was observed in the case of dry biomass at maximum tillering stage (Table 1), but no statistically significant difference was observed at harvesting between microwave treated plots (27.8 t $ha^{-1}$) and untreated control plots (22.8 t $ha^{-1}$).

Dryland wheat production is strongly influenced by weed management practices. The application of MW into soil for pre-emergence weed control significantly increased the dryland wheat productivity (Table 1). The 50.9% gain in fresh weight and 42.4% gain in dry weight, compared with the control plots, were acquired from the MW treated plots. Tiller density is the main contributor of final grain yield. The maximum number of tillers was developed in the MW treated plots (387 $m^{-2}$) compared to the untreated control plots (268 $m^{-2}$). In the present investigation, the final incremental increase of 33.1% in dry biomass production and 39.2% in grain yield was attained through MW energy application into the soil for weed management.

## DISCUSSION

The higher crop productivity could be attributed to a 70–80% reduction in weed establishment achieved through MW irradiation of soil, ultimately leaving more room for crop growth. Thermal devitalisation of weed seedbanks in the top soil layer may be the possible cause of minimum weed interference with the various crops. This was evidenced by (Vidotto *et al*. 2013), who explored the effectiveness of high temperature on seed viability of six weed species including *Echinochloa crus-galli* (L.) P.Beauv., a problematic weed of rice regions globally. They stated that 80–100% germination reduction was achieved through raising the soil temperature to 79.6°C. This

**Table 1.** Comprehensive view of microwave weed control on the productivity of rice and wheat crop under field conditions at Dookie, Victoria. Different superscripts across the row depicting a significant difference at 5% probability level.

| Agronomic crop characteristics | Rice | | | | Wheat | | | |
|---|---|---|---|---|---|---|---|---|
| | Soil treatments | | | | Soil treatments | | | |
| | Microwave treated | Untreated control | $LSD_{5\%}$ | % change | Microwave treated | Untreated control | $LSD_{5\%}$ | % change |
| Number of tillers ($m^{-2}$) | 419[a] | 292[b] | 113.9 | 43% | 387[a] | 268[b] | 62.0 | 44.4% |
| Fresh biomass weight (t $ha^{-1}$) [a] | 46.3[a] | 25.1[b] | 9.4 | 84.6% | 30.8[a] | 20.4[a] | 10.4 | 50.9% |
| Dry biomass weight (t $ha^{-1}$) | 27.8[a] | 22.8[a] | 6.04 | 21.9% | 19.7[a] | 14.8[b] | 4.8 | 33.1% |
| Grain yield (t $ha^{-1}$) | 9.0[a] | 6.7[b] | 2.04 | 34.38% | 7.8[a] | 5.6[b] | 2.3 | 39.2% |
| Partial factor productivity of nitrogen (kg grain kg $N^{-1}$) [b] | 72 | 53.6 | – | – | 65 | 46 | – | – |

[a] Data collection at maximum tillers establishment for both crops (60 days after sowing).

[b] Partial factor productivity of nitrogen (PFP) $=\frac{Y_0}{N_r}+\frac{\Delta Y}{N_r}$, change in crop yield with nitrogen application was calculated based on work done by (Cassman *et al.* 1998).

Note: Applied nitrogen during cropping period of rice was 125 kg N $ha^{-1}$ and for wheat 120 kg N $ha^{-1}$.

is the same temperature range (70–80°C) that was acquired by MW irradiation of the soil in the present study. This effectively induced an inhibitory effect on the weed population and therefore increased the rice crop yield. These results are strongly supported with findings of other work (Brodie 2016).

An increase in crop dry biomass was also reported by Gibson *et al*. (1988) who demonstrated that shoot dry biomass of birch significantly increased in MW irradiated soil. Their experiment was to evaluate the effect of MW treatment of soil supplemented with two mycorrhizae on birch seedlings; the shoot dry biomass progressively increased with irradiation duration of soil, with the highest dry shoot biomass being 84 mg for MW irradiation.

In addition to weed suppression, numerous studies have reported the supplementary effect of MW irradiation of soil on crop growth. However, the exact reason for good crop growth and development in MW treated soil is still in question. It has been demonstrated that MW irradiation markedly alters the physical and chemical properties of soil organic matter (SOM; Hur *et al*. (2013)) and enhances the humification of SOM (Kim and Kim 2013). Relevant to this, SOM is aggregates of organic residues in soil at different stages of humification. Thermal denaturation of these biopolymers, induced by MW irradiation, could increase the concentrations of free amino acids for succeeding turnover to $CO_2$ and the ammonia pool ($NH_4^+$), which might have led to higher yield of the crops in MW treated soil, in the present investigations.

## ACKNOWLEDGMENTS

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