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Section 2

Weeds

Burning of weed seeds in low rainfall farming systems

RESEARCH

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Key messages

- **Seeds of all species could be killed with heat, however there were differences in tolerance to heat.**
- **Duration of heat treatments had a significant impact on the efficacy on weed seeds in all species.**
- **Seeds of most weed species could be killed by simulating conditions similar to burning narrow harvest windrows.**
- **The efficacy of narrow windrow burning in the field is largely determined by the proportion of weed seeds that can be collected by the header and placed into harvest windrows.**

Why do the trial?

Weeds are one of the largest costs to grain producers and a primary driver in how cropping systems are managed. Weeds are estimated to cost Australian grain growers $3,318 million annually (Llewellyn *et al*. 2016). Weeds will continue to drive crop management systems as weed challenges evolve, particularly from herbicide resistance. This will increase the importance of cultural control methods as part of any integrated weed management (IWM) strategy. Burning crop residues to destroy weed seeds is one of the oldest cultural weed control measures in agriculture. While information exists on annual ryegrass and wild radish efficacy from burning crop residues (Gill and Holmes, 1997; Walsh and Newman, 2007), little is known about other weed species. This study aims to investigate the potential of crop residue burning to control weeds that are problematic for low rainfall cropping systems in southern Australia. A method similar to Walsh and Newman (2007) was used to simulate different levels of heat (temperature) and duration experienced during crop residue burning on weed seeds.

How was it done?

Seed collection

Seeds of 10 different weed species were collected from cropping fields at weed maturity (Table 1). Seed was cleaned and removed from associated structures for all species except Mallow that was left in individual seed pod segments. This was done to achieve consistency with the state of weed seeds shedding at the time of stubble burning. Seeds were counted and placed into packets of 100 seeds.

Heat treatment

A kiln (Woodrow GK63TL top loading glass kiln) was used to apply heat treatments to seeds. The kiln was preheated to the desired temperature. Seed of each species were placed in a ceramic dish, held in a rack and swiftly placed into the kiln for the desired duration. Seed was allowed to cool in the dishes and placed back into their packets for later germination assessment. Temperature readings from the kiln were calibrated against a laboratory infrared thermometer (MIKRON IR-MAN model 15t) shown below in Table 2.

Table 1. Weed seeds and district of origin.

Weed species	Scientific name	Region
Barley grass	*Hordeum glaucum*	Upper Eyre Peninsula
Brome grass	*Bromus diandrus*	*Northern Yorke Peninsula & Mallee
Wild oats	*Avena fatua* - (1)	Lower North
Wild oats	*Avena fatua* – (2)	Upper Eyre Peninsula
Annual ryegrass	*Lolium rigidum*	‘safeguard ARG’ control species
Onion weed	*Asphodelus fistulosus*	Upper Eyre Peninsula
Statice	*Limonium lobatum*	Upper North
Mallow	*Malva parviflora*	Upper North
Indian hedge mustard	*Sisymbrium orientale*	Lower North
Lincoln weed	*Diplotaxis tenuifolia*	Upper Eyre Peninsula
Wild turnip	*Brassica tournefortii*	*Mallee & Upper North

** composite population, Mallow was treated in individual seed pod segments*

Table 2. Kiln temperature calibration against laboratory infrared thermometer (IRT).

Kiln temp	200°C	250°C	300°C	350°C	400°C	450°C
IRT temp	200.1°C	246°C*	300°C	355.3°C	400.6°C	451°C

*IRT temp mean of multiple readings, * kiln set to 255°C to achieve correct temperature*

Germination assessment

Treated seed packets were placed in petri-dishes with 2 filter paper discs on the base. 10 mm of 0.001M Gibberellic acid (GA) solution was applied to the seed, brome grass and barley grass requiring 12.5 mm and wild oats requiring 15 mm GA solution. Dishes were then sealed with parafilm and then all 19 dishes (single replicate of each weed species) was wrapped in two layers of aluminium foil and placed into a controlled environment growth room (Phoenix systems) at 20°C/12°C day/night temperature for approximately 14 days, at which time both germinated and non-germinated seeds were counted. At 14 days mallow seeds were counted and individual seeds were removed from seed pod segments. Mallow seeds that were deemed to be potentially viable (still hard), but not germinated were knicked with a scalpel and placed back onto dishes with fresh GA solution and returned to growth room for a further seven days when germination was again assessed. Wild oat populations were given extended time in the growth room, but failed to germinate and were excluded from the trial.

Trial details and analysis

The trial was replicated three times with 100 seeds in each sample. Germination in each dish was compared back to the relevant untreated control. This was then statistically analysed using an analysis of variance using GENSTAT 15th Edition statistical computer program.

What happened?

The ability of weed seeds to tolerate heat varied considerably between species with Lincoln weed seed being the most susceptible and mallow seed being the most tolerant to heat (Table 2). Germination data was plotted against a heat index (HI = temperature °C x duration seconds), and a sigmoidal logistic 3 parameter model was fitted using SigmaPlot 12.5 v002 statistical program. Parameter X_0 from the fitted model represents the HI units required to suppress seed germination by 50%. X0 values were used to rank weed species for tolerance to heat. Tolerance of weed seeds to heat was not closely related to seed size or weed type. Brassica seeds with their smaller size and high oil content would be expected to be more sensitive to heat. This was the case for both Lincoln weed and Indian hedge mustard (IHM) which were the two most susceptible weed species to heat. However wild turnip, another brassica weed, was the second most tolerant species studied. Larger seed size did not correlate with tolerance to heat, with smaller seeded ryegrass showing greater tolerance to heat than larger brome or barley grass seeds.

Grass weeds

Barley grass has become a serious weed of many low rainfall cropping systems due to increased seed dormancy and incidence of herbicide resistance (Fleet *et al*. 2012; Shergill *et al.* 2015). The effect of heat, like that produced from burning crop residues, on barley grass was found to be strongly influenced by both temperature and duration (Table 4). Barley grass seed was completely killed at 350°C, but only at a duration ≥60 seconds. However, barley grass seed kill was significantly reduced at shorter durations. Exposure of barley grass seeds to 300°C for a duration of 60 seconds could halve barley grass seed viability. However, the same level of control could be achieved by exposure to >450°C for 20 seconds.

Table 3. Ranking of weed seed tolerance to heat from least to the most tolerant, P<0.0001.

Rank	Weed	X_0 for HI (SEM)	HI R^2
1	Lincoln weed	6231 (325)	0.78
2	Indian Hedge Mustard	10021 (929)	0.70
3	Onion weed	15028 (391)	0.77
4	Barley grass	16043 (373)	0.82
5	Brome grass	16070 (562)	0.73
6	Statice	16618 (298)	0.88
7	Annual ryegrass	17505 (474)	0.78
8	Wild turnip	18405 (484)	0.74
9	Mallow	21197 (1413)	0.44

SEM - Standard error mean

Based on the results of stubble burn temperatures from Walsh and Newman (2007), effective control of barley grass seed is only expected in heavy windrows or narrow windrows. Burning a standing stubble is unlikely to be effective in killing barley grass seed. Unfortunately, most barley grass seed has shed well before crop harvest and is unlikely to end up in the windrow for burning or captured by harvest weed seed capture (HWSC) systems. In a field trial in the Upper North, Fleet *et al*. (2014) found that when wheat was harvest-ready, <1% of barley grass had the potential of being collected, with the remainder either being shed onto the ground or below 10 cm in height. Similar results were found in plot studies where <6% of barley grass seed remained on the panicles when wheat was harvest-ready (Kleemann *et al*. 2016). Therefore, the effectiveness of windrow burning against barley grass is expected to be rather low.

The response of brome grass to high temperature exposure was very similar to barley grass (Table 5). Effective kill of brome grass seed is also likely to require crop stubble to be burnt in either a heavy row or narrow windrow to achieve required temperatures and duration of heat. Contrary to barley grass, brome grass is capable of retaining 75% of its seed on the panicle by earliest crop harvest. However brome grass plants can often lodge and fall below the harvest cutting height. In a field trial at Roseworthy, depending on weed density, 30-80% of brome grass panicles were below the height of crop harvest at earliest crop harvest (Kleemann *et al*. 2016). Despite this, HWSC followed by burning of windrows could provide some level of control of brome grass.

While ARG seed was found to be the most heat tolerant of the grass weeds trialled (Table 3), it followed a similar trend to brome and barley grass (Table 6). ARG required approximately 100°C more heat at equivalent duration than either brome or barley grass to achieve a high level of weed seed control. These results show ARG to be more tolerant to heat than previously reported by Walsh and Newman (2007). Given the temperatures required to control ARG seeds, HWSC tactics where harvest residue is placed in heavy rows or preferably narrow windrows for burning would be required. A South Australian study of the potential of HSWC tactics found that between 26-73% of annual ryegrass seed could potentially be captured and then placed in narrow windrows for burning (Fleet *et al*. 2014). While still highly variable, depending on the timing and seasonal conditionals, ARG has the potential for significant seed control with HWSC tactics and narrow windrow burning. Ranking of these grass species would be barley grass: unviable < brome grass some control < annual ryegrass moderate control.

Table 4. Effect of heat on Barley grass seed viability (% survival).

	Temperature (°C)					
Duration (s)	**200**	**250**	**300**	**350**	**400**	**450**
20	97 *a*	100 *a*	97 *a*	97 *a*	94 *a*	57 *bc*
40	96 *a*	100 *a*	100 *a*	62 *b*	**19 *d***	**0 e**
60	97 *a*	96 *a*	51 *c*	0 *e*	**0 e**	**0 e**

P<0.001, LSD=9.666, cv rep=5.6%, >80% reduction ***bolded***

Table 5. Effect of heat on Brome grass seed viability (% survival).

	Temperature (°C)					
Duration (s)	**200**	**250**	**300**	**350**	**400**	**450**
20	100 *a*	98 *a*	100 *a*	91 *a*	71 *b*	68 *b*
40	97 *a*	93 *a*	98 *a*	59 *b*	**7 c**	**0 c**
60	98 *a*	89 *a*	72 *b*	**2 c**	**0 c**	**0 c**

P<0.001, LSD=16.07, cv rep=5.8%, >80% reduction ***bolded***

Table 6. Effect of heat on Annual ryegrass seed viability (% survival).

	Temperature (°C)					
Duration (s)	**200**	**250**	**300**	**350**	**400**	**450**
20	93 *ab*	98 *a*	98 *a*	98 *a*	93 *ab*	70 *b*
40	98 *a*	97 *a*	99 *a*	73 *b*	54 *c*	**0 e**
60	99 *a*	95 *ab*	82 *b*	21 *d*	**1 e**	**0 e**

P<0.001, LSD=14.44, cv rep=3.2%, >80% reduction **bolded**

Table 7. Effect of heat on Onion weed seed viability (% survival).

	Temperature (°C)					
Duration (s)	**200**	**250**	**300**	**350**	**400**	**450**
20	94 *ab*	93 *ab*	88 *ab*	90 *ab*	82 *b*	38 *c*
40	91 *ab*	89 *ab*	91 *ab*	31 *c*	**1 *d***	**0 *d***
60	87 *ab*	86 *ab*	**11 *d***	**0 *d***	**0 *d***	**0 *d***

P<0.001, LSD=15.31, cv rep=7.9%, >80% reduction **bolded**

Table 8. Effect of heat on Statice seed viability (% survival).

	Temperature (°C)					
Duration (s)	**200**	**250**	**300**	**350**	**400**	**450**
20	96 *ab*	95 *ab*	96 *ab*	100 *a*	99 *a*	83 *b*
40	98 *ab*	92 *ab*	97 *ab*	76 *b*	46 *c*	**4 e**
60	94 *ab*	91 *ab*	48 *c*	24 *d*	**2 e**	**4 e**

P<0.001, LSD=14.50, cv rep=3.3%, >80% reduction **bolded**

Broad-leaved weeds

Onion weed seed was more sensitive to heat than the grass species studied (Table 7.). Onion weed is usually found in areas of poor competition in crops and pastures (Pitt *et al*. 2006). Despite the potential of heat to control onion weed seeds it could be difficult to have enough crop or pasture biomass to achieve enough heat and duration for effective control, particularly if burning pasture residues or standing stubble. Such paddocks are also prone to wind erosion so the implications of burning need to be considered carefully.

Statice seed was significantly more tolerant of heat than onion weed (Table 3). It required temperatures ≥400°C for 60 s duration to achieve effective control of statice seeds. From the stubble burning temperatures reported in Walsh & Newman (2007), HWSC and narrow windrow burning would be required to possibly achieve effective control of statice seed. This species shows potential of HWSC techniques as it appears to retain seed pods and is often a grain contaminant in problem paddocks, however will require very hot and prolonged stubble burning conditions. As statice is often found in paddocks affected by some level of salinity, the level of crop residue present may be inadequate for achieving prolonged hot burn.

Mallow seed was treated in small pod segments as by autumn when crop residues are burnt the primary mallow pods have broken up and individual pod sections remain. Mallow was found to be extremely heat tolerant and would likely prove very difficult to control in many stubble burning situations. It was found to require ≥450°C for ≥40 seconds to obtain effective control of seeds (Table 9). At 450°C there was no seed kill at 20 seconds duration, but high levels of control at 40 seconds duration, indicating a critical heat duration time between 20-40 seconds at this temperature. Mallow was the most heat tolerant weed species in this study (Table 3).

Brassica weeds

Lincoln weed seed was found to be the most sensitive weed species to high temperature exposure in this study (Table 3). Like other species, Lincoln weed seed control was dependent on both temperature and duration. However once temperature was ≥350°C, effective control could be achieved even with 20 s exposure (Table 10.). This indicates that there would be some potential to control Lincoln weed in standing stubble situations. An additional complication would be that such a small seed could fall between soil clods or cracks and be insulated from any heat caused by burning. Walsh and Newman (2007) reported that as little as 1 cm of soil cover could effectively insulate seed from heat produced from residue burning. Lincoln weed would not be suited for HWSC and narrow windrow burning as it is generally a weed of summer fallows where it grows after crop harvest.

Table 9. Effect of heat on Mallow seed viability (% survival).

	Temperature (°C)					
Duration (s)	**200**	**250**	**300**	**350**	**400**	**450**
20	100 *a*	92 *ab*	95 *ab*	100 *a*	100 *a*	100 *a*
40	97 *ab*	75 *ab*	100 *a*	100 *a*	92 *ab*	**3 c**
60	92 *ab*	88 *ab*	95 *ab*	44 *b*	66 *b*	**9 c**

*P<0.001, LSD=32.26, cv rep=3.1%, >80% reduction **bolded***

Table 10. Effect of heat on Lincoln weed seed viability (% survival).

	Temperature (°C)					
Duration (s)	**200**	**250**	**300**	**350**	**400**	**450**
20	97 *a*	92 *a*	62 *b*	**11 c**	**0 c**	**0 c**
40	49 *b*	**18 c**	**0 c**	**0 c**	**0 c**	**0 c**
60	**18 c**	**3 c**	**0 c**	**0 c**	**0 c**	**0 c**

*P<0.001, LSD=28.87, cv rep=17.1%, >80% reduction **bolded***

Table 11. Effect of heat on Indian Hedge Mustard seed viability (% survival).

	Temperature (°C)					
Duration (s)	**200**	**250**	**300**	**350**	**400**	**450**
20	71 *b*	66 *bc*	88 *a*	54 *c*	69 *b*	**0 e**
40	73 *b*	53 *c*	47 *c*	**0 e**	**0 e**	**0 e**
60	69 *b*	**19 *d***	**1 e**	**0 e**	**1 e**	**0 e**

*P<0.001, LSD=12.55, cv rep=4.2%, >80% reduction **bolded***

Table 12. Effect of heat on Wild Turnip seed viability (% survival).

	Temperature (°C)					
Duration (s)	**200**	**250**	**300**	**350**	**400**	**450**
20	98 *a*	98 *a*	98 *a*	100 *a*	100 *a*	99 *a*
40	99 *a*	99 *a*	98 *a*	99 *a*	92 *a*	**0 c**
60	100 *a*	99 *a*	98 *a*	32 *b*	**0 c**	**0 c**

*P<0.001, LSD=21.40, cv rep=3.7%, >80% reduction **bolded***

IHM seed was found to be more tolerant of heat than Lincoln weed (Table 3). While temperatures ≥450°C could completely control IHM seed at the shorter duration times, duration times of ≥60 seconds were required to achieve effective control at 250-300°C (Table 11). According to the temperature and duration results reported by Walsh and Newman (2007), potentially enough heat would be generated for long enough to effectively control IHM seed when either burning heavy conventional or narrow harvest windrows. IHM is also well suited for HWSC followed by windrow burning as it has high pod and seed retention (Fleet *et al.* 2016).

Wild turnip seed was found to be one of the most heat tolerant of the weed species studied, particularly when compared to other brassica weeds. Wild turnip was nearly 2 and 3 fold more tolerant than IHM and Lincoln weed, respectively (Table 3). Wild turnip required ≥400°C for 60 seconds to effectively kill seeds; a 40 second duration achieved the same results when temperature was increased to 450°C. However at 450°C, 20 second heat duration had no effect on seed viability (Table 12). Narrow windrow burning of stubble would be the only way to potentially achieve the temperatures and durations required to effectively control wild turnip seed (Walsh and Newman, 2007). Wild turnip is unlikely to be well suited to HWSC and narrow windrow burning as it is prone to shed seeds early before crop harvest.

What does this mean?

All weed species investigated showed that exposure to heat could provide control of seeds, but there were large differences between weeds in their tolerance to heat. Combinations of high temperature and exposure time investigated could provide complete kill of all species except marshmallow. High temperature and duration of burn expected from burning narrow windrows should provide effective seed kill of most of these species. However, the performance of this method is completely dependent on how much of the weed seeds can be collected at harvest (HWSC) and placed into narrow harvest windrows. Grass weeds all showed similar patterns of tolerance to heat with ARG being the most tolerant. Despite the higher tolerance to heat, high pre-harvest seed retention in ARG makes it more suited to effective control from residue burning (narrow windrows) than barley grass, which sheds most of its seeds well before harvest. Among brassica weeds, IHM showed good potential for control by burning harvest windrows as it is sensitive to both heat and HWSC methods.

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