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Burning narrow windrows for weed seed destruction

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Abstract

The recently developed technique of burning narrow windrows to kill weed seeds has been extensively adopted by WA crop producers. A chute mounted to the rear of the grain harvester concentrates harvest residues including weed seed into narrow windrows in preparation for burning the following autumn. Preliminary kiln studies determined that temperatures in excess of 400 °C for at least 10 s were needed to guarantee the death of ryegrass seeds while 500 °C for the same duration was required to kill wild radish seed within their pod segments. The effectiveness of burning narrow windrows of crop residues in killing annual ryegrass and wild radish seed was evaluated over four seasons in the northern wheatbelt region of Western Australia. Burning standing stubble was found to be less effective in killing annual ryegrass and wild radish seed present on the soil surface, than either burning conventional or narrow windrows. Higher biomass levels in narrow windrows increased the mortality of annual ryegrass and wild radish through burning by increasing both burning temperatures and duration of these higher temperatures. Although burning exposes the soil surface, increasing the potential for erosion, strategic burning of narrow windrows significantly reduces the erosion risk where, depending on harvester width, generally less than 10% of field area is exposed by this practice.

Keywords: Annual ryegrass; *Lolium rigidum*; *Raphanus raphanistrum*; Wild radish; Windrow burning

1. Introduction

Annual ryegrass (*Lolium rigidum* Gaud.) and wild radish (*Raphanus raphanistrum* L.) are the two most problematic weeds of Western Australian crop production systems (Alemseged et al., 2001). They are highly competitive weeds causing substantial yield losses from relatively low densities (Cheam and Code, 1995; Lemerle et al., 1996; Cousens and Mokhtari, 1998; Hashem and Wilkins, 2002) and their ability to establish large, long lived seedbanks ensures their persistence in crop production systems (Reeves et al., 1981). Preventing inputs to the seedbank is an effective means of reducing the impact of these weeds on subsequent crops. The evolution of herbicide resistance in annual ryegrass (Owen et al., 2005) and wild radish (Walsh et al., 2005) means that targeting the seed of these species also prevents the input of resistant seed into the seedbank.

Several techniques have been developed to collect and remove or destroy the weed seed containing fraction of the harvest residue. Both annual ryegrass and wild radish seed exit in the chaff fraction during harvest and the collection of this material in "chaff carts" allows the removal of 75–85% of ryegrass seed and 70–80% of wild radish seed entering the harvester (Walsh and Parker, 2002).

Baling harvest residues collected from the soil surface or directly from the rear of the harvester has also been shown to allow the collection of 50 and 95%, respectively of ryegrass seed entering the harvester (unpublished data). However, despite these results, chaff carts and baling systems are not widely adopted by Western Australian grain growers due to a number of limitations including reduced harvest capacity, machinery break downs and capital costs.

A small number of growers began using the practice of burning narrow windrows in 2001 using a chute mounted to the rear of the harvester to concentrate the straw and chaff residues into a narrow (500–700 mm wide) windrow. These windrows were then burnt 4 to 5 months after harvest during the burning season that commences in mid- to late March in most shires across the WA wheatbelt. A recent survey in March 2005 of 72 growers in the Northern Agricultural Region of Western Australia revealed that 50% of growers were using the practice

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of windrow burning to destroy weed seeds. Of those practicing windrow burning, 69% used a chute mounted to the rear of the harvester to create narrow windrows (Newman unpublished data).

If windrow burning generates temperatures high enough to destroy weed seeds present in the harvest residue, then similar levels of weed seed control can be expected from burning narrow windrows as is achieved by using chaff carts or residue baling. Stubble burning is probably the oldest form of weed seed control, however, there is very little information on the effectiveness of this practice as a means of destroying weeds seeds. A series of experiments were conducted to compare the burning of standing stubbles versus windrowed harvest residues in destroying annual ryegrass and wild radish seed. The influence of residue level and arrangement as well as wind speed on the efficacy of burning were also investigated.

2. Methods

2.1. Kiln experiment

A kiln experiment was carried out to establish the temperature and duration required for annual ryegrass and wild radish seed to lose viability. Lots of 100 annual ryegrass and wild radish seed within their pod segments were placed in porcelain vessels then heated, at pre-determined temperatures and for specific time periods. Three replicate seed lots were used for each temperature, duration and seed type. Following heating, seeds were allowed to cool, wild radish pod segments carefully dissected to recover the seed. Germination tests were undertaken with the seed placed on 1% (w/v) water based agar in Petri-dishes, and incubated for 14 days at 25/15 °C day/night temperatures with a 12 h photoperiod. After this period, annual ryegrass and wild radish seeds were classified as viable if they had germinated or remained firm and not decayed.

2.2. Standing stubble versus conventional windrows

Investigations on the effects of burning windrows and standing stubble on survival of annual ryegrass seed were conducted at York (31°95′S, 116°89′E) in the autumn of 2003. An annual ryegrass free site was chosen and fixed amounts of viable, non-dormant annual ryegrass seed were added to the front of the harvester during harvest. Standing and windrowed stubble treatments were established during the harvest of the wheat crop. The conventional stubble windrow was created by allowing the harvest residue to drop onto the ground out of the back of the harvester creating a 1.2 m wide windrow. Straw spreaders were used in the standing stubble treatment to spread the chaff and straw material evenly across the width of the swath as it exited the harvester. Postharvest residue sampling across the stubble treatment plots was conducted to determine the stubble biomass levels and ryegrass seed numbers present on the soil surface. From six chaff samples collected at harvest, it was determined that approximately 1600 seeds exited the harvester in the chaff fraction per metre of windrow.

Burning treatments were conducted on the 15th April 2002, with thermocouples located at four heights within the windrow and standing stubble treatments used to measure burning temperature and duration, these were (i) 1 cm below the soil surface, (ii) on the soil surface, (iii) 10 cm above the surface, and (iv) 20 cm above the surface. Temperatures were recorded during burning of the stubble treatments at one s intervals using high temperature type K thermocouples (composed of NiCu/NiAl) connected to a CR10X Campbell Scientific datalogger[1]. Thermocouples were placed at a range of heights beneath or above the soil surface to record the temperature and duration of the burning treatments in the first study examining standing versus conventional windrows. For subsequent studies probes were placed on the soil surface and temperatures were recorded at 5 s intervals.

A growing-season commencing rainfall event occurred 16–18 April, with 17 mm recorded at the site. Counts of emerged annual ryegrass seedlings were conducted 2 weeks later where the number of seedlings in a 0.25 m^2 quadrat was determined at nine locations in each strip.

2.3. Narrow versus conventional windrow and standing stubble

During the 2003 harvest, a site was established to investigate the burning efficacy of narrow and conventional harvest residue windrows with standing stubble in a wheat field at Konnongorring (31°03′S, 116°47′E 31). Temperatures were recorded on the soil surface at three locations (replicates) during burning of each stubble treatment on 24 March (Fig. 3). Burning was conducted in mid-afternoon during the warmest part of the day.

A chute mounted to the rear of the harvester concentrated harvest residues into a narrow windrow 600–700 mm, conventional windrows that were created by allowing harvest residues to fall to the soil surface into a 1.2–1.4 m windrow. Consequently, the biomass per m^2 in a narrow windrow was approximately double that of conventional windrows.

2.4. Harvest residue level effects on burning temperatures

During the 2004 harvest a site was established at Mingenew (29°24′S, 115°22′E) to investigate the effects of stubble level and wind direction on the burning temperatures of lupin stubble. Two harvest residue levels (high and low) were established in narrow windrows during harvest by varying the width of the harvest swath. High stubble level was established from a 9 m swath and a 3 m swath established the low residue level windrow. Stubble burning was conducted on two occasions 3 weeks apart with the first on 30 March 2005 and the second on 24 April 2005. Prior to burning each windrow treatment 100 annual ryegrass seed and 100 wild radish pod segments were placed on the soil surface contained within two 15 cm diameter aluminum dishes (filled with soil) respectively.

[1] Campbell Scientific, 16 Somer St Hyde Park, Townsville, Qld 4812, Australia.

Aluminium dishes were buried and filled with soil so that the weed seed were at ground level. Temperature probes were placed on the soil surface beneath each windrow treatment prior to burning. Temperatures were recorded at 5 s intervals during windrow burning as described above. After the completion of burning wild radish and annual ryegrass seed were recovered from the dishes and their viability was determined using the germination test described above.

2.5. Crop residue type and wind speed effects

During autumn of 2006 the effect of wind speed on the burning temperatures of narrow windrows of lupin, canola and wheat harvest residues was determined. The temperature at the soil surface was recorded during the burning of narrow windrows of each of these crops where three wind speeds, high, medium and low, were imposed. The low wind speed was created by shielding the burning windrow from the prevailing wind with a tarp. The medium wind treatment was the prevailing wind occurring during burning. The high wind speed was created using a leaf blower. Wind speed was recorded at 5 s intervals using an anemometer mounted 30 cm from the soil surface attached to a CR10X data logger. Soil surface temperatures were also recorded at 5 s intervals, as described earlier.

2.6. Trial designs, data collection and analysis

Experiments comparing crop residue treatments (standing stubble, conventional windrow and narrow windrow) were established in randomised block designs with three replicates. Within each plot, residue samples were collected from a representative 1.0 m^2 of stubble or 1.0 m length of windrow. In the harvest residue-type and residue-level experiments, 3×1.0 m windrow lengths of each treatment were sampled just prior to burning, with temperature probes then placed in residue sections adjacent to where these samples were taken. Temperatures recorded were averaged for each 1 or 5 s reading from the commencement of burning in each treatment. A heat index (HI) was derived by summing the temperature achieved above ambient, each second, for the time of the burn was used to relate burning intensity to biomass. Effective burning time (EBT) was determined as the time in seconds when the burning temperature was above 300 °C and was calculated for each burning treatment. An analysis of variance was performed on HI, EBT, and maximum temperature values recorded during burning using Genstat (ver. 7.2.0). Means were separated using Tukeys HSD where $p = 0.05$. There were no significant differences in these values between crop types within each wind speed treatment, therefore, temperature data for the three crop types were pooled for presentation of wind speed effects.

3. Results and discussion

3.1. Kiln experiment

A temperature of 400 °C was required to kill annual ryegrass seed during a 10 s exposure to this temperature, with longer exposure periods required as temperatures declined (Table 1). Wild radish seed within their pod segments were more resilient to higher temperatures than ryegrass with a 10 s exposure to 500 °C needed to kill all wild radish seed (Table 1).

The relationship between HI and seed mortality in this experiment proved only indicative accounting for only 76 and

Table 1
Effect of temperature and duration of exposure, on the percentage germination of (A) Annual ryegrass and (B) wild radish

	Survival (%)					
	200 °C	225 °C	250 °C	275 °C	300 °C	400 °C
(A) Annual ryegrass duration (s)						
10	–	–	–	–	77	0
20	92	70	55	57	5	0
40	90	26	15	6	0	0
60	89	1	0	0	0	0
80	74	0	0	0	0	0

	Survival (%)				
	300 °C	350 °C	400 °C	450 °C	500 °C
(B) Wild radish duration (s)					
10	89	88	85	22	0
20	89	67	1	0	0
60	1	1	0	0	0

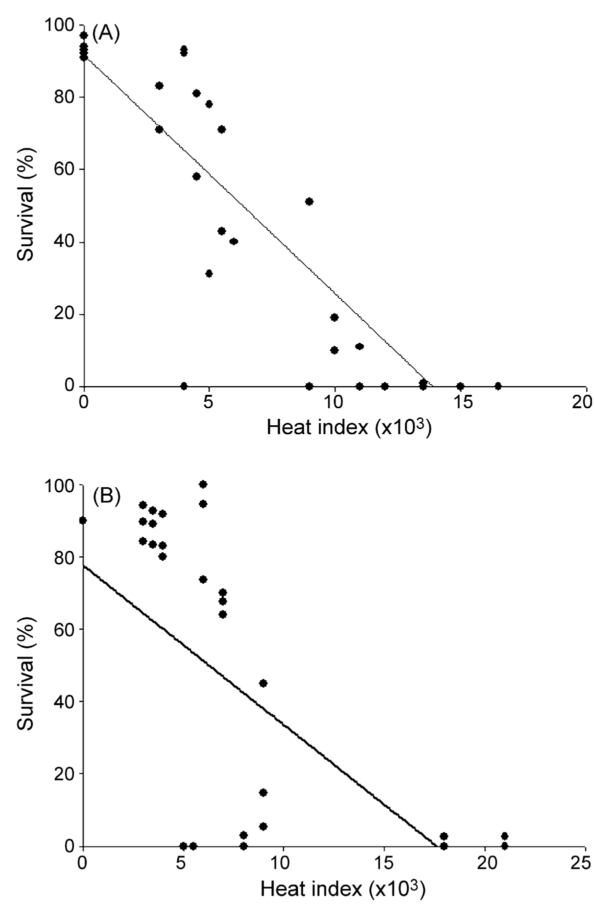

Fig. 1. Relationship between heat index (HI) and seed mortality of *Lolium rigidum* ($r^2 = 0.76$) (A) and *Raphanus raphanistrum* ($r^2 = 0.44$) (B) as determined by exposing seed to high temperatures for short durations.

44% of the variation in annual ryegrass ($r^2 = 0.76$) and wild radish ($r^2 = 0.44$) seed mortality respectively (Fig. 1). Therefore, HI values were calculated in subsequent burning treatments but only used as an indication of the potential efficacy of these treatments in killing annual ryegrass and wild radish seed.

3.2. Standing stubble versus windrow stubble burning

Temperatures recorded by the above ground thermocouples were uniformly higher during burning of the conventional windrow treatment compared to those recorded during the burning of the standing stubble (Fig. 2, Table 2). Elevated temperatures persisted for 200 s after the narrow windrow started burning. In contrast the soil surface temperature was almost back to the ambient level in just over 50 s in the standing stubble treatment.

In the windrow treatment all above ground temperature readings were high enough to kill annual ryegrass seed. In comparison it was only at the 10 and 20 cm heights in the standing stubble treatment that complete annual ryegrass seed kill would likely have occurred. In March, annual ryegrass seed are typically only found on the soil surface (Davidson, 1994) in wheat stubble fields, therefore, the temperatures recorded at the soil surface during burning will provide the clearest indication of how effective a burning treatment is likely to be in killing weed seeds. The conventional windrow burning treatment

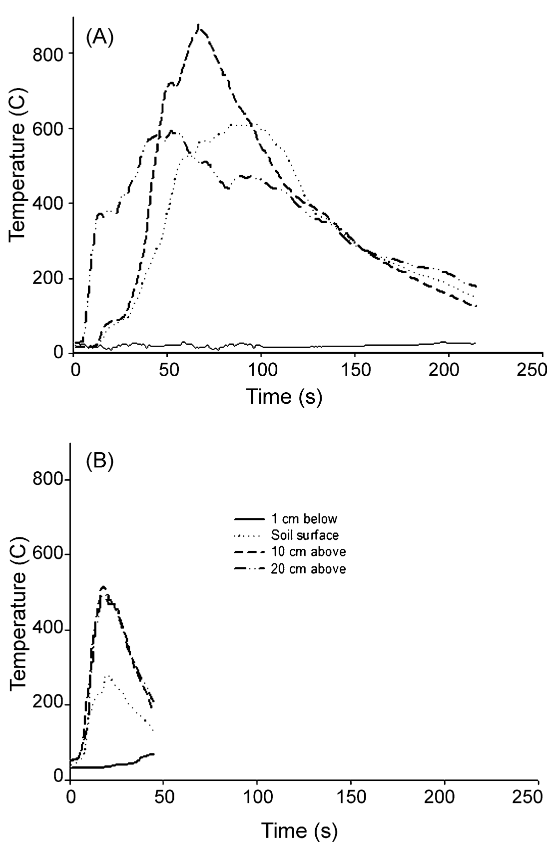

Fig. 2. Temperatures measured at four heights from the commencement of burning a conventional windrow (A) and standing stubble (B) at York in 2002.

Table 2
Effect of wheat stubble treatments on the maximum burning temperatures, Heat Index and EBT recorded on the soil surface during burning at York 2002

Stubble treatment	Maximum temperature (°C)	Heat index ($\times 10^3$)	EBT (s)
Standing	406.3	10.5	17
Conventional windrow	555.3	30.6	68
LSD ($P = 0.05$)	232.7	2.7	96

produced a significantly ($P < 0.05$) higher HI value compared to that of the standing stubble treatment (Table 2). There was a hotter and longer burn in the windrow treatment which resulted in higher temperatures being recorded at the soil surface for a longer period when compared with the standing stubble treatment. As higher HI values indicate an increased chance of seed mortality (Fig. 1) then the HI values from the windrow burning treatment clearly indicate the increased potential for the destruction of annual ryegrass and wild radish seed.

The averaged temperature data plotted in (Fig. 2) does not reflect the variability in temperatures that occurred during burning of individual treatment replicates. The data plotted are the averaged replicate data for each time of recording commencing from when temperatures on the soil surface began to increase due to the effects of burning stubble. There was considerable variability in recorded temperatures at particular time points. This is indicated by the very large LSD values calculated for the comparison of maximum temperatures, HI and EBT. Temperature readings fluctuated markedly both within and between treatments as indicated by large LSD's and subsequent lack of significant differences between treatments. This variability was also evident in subsequent temperature measurements comparing stubble level and wind speed effects. Therefore, the data presented in Fig. 2 and indeed for later figures represents the averaged results for each point in time while maximum temperature values presented in Tables 2–4 were those recorded at any time during the measurement period.

Windrow burning was more effective than standing stubble burning in reducing annual ryegrass seedling emergence at the start of the subsequent growing season. Only 1% of the ryegrass seed placed in the windrow burning treatment subsequently emerged as seedlings the following autumn (Fig. 3). In contrast, 20% of the ryegrass seed in the stubble burning treatment survived burning. Although it is possible that there may have been some ryegrass seed removal by predation over summer (Spafford Jacob et al., 2006) these results clearly show that the

Table 3
Effect of stubble level on the maximum temperatures, Heat Index and EBT recorded during the burning of two levels of lupin stubble in narrow windrows at Mingenew in 2005

Stubble level	Maximum temperature (°C)	Heat index ($\times 10^3$)	EBT (s)
Low (14 t ha^{-1})	423	126	142
High (28 t ha^{-1})	428	210	264
LSD ($P = 0.05$)	237	96	213

Table 4
Effect of wind speed on the maximum burning temperature, Heat Index and EBT of wheat, canola and lupin stubbles at Mullewa in 2006

Wind speed	Maximum temperature (°C)		
	Wheat ($50\ t\ ha^{-1}$)	Canola ($52\ t\ ha^{-1}$)	Lupins ($68\ t\ ha^{-1}$)
Low	435	600	540
Medium	454	714	763
High	878	–	583
LSD ($P = 0.05$)	169	71	453
EBT (s)			
Low	601	735	613
Medium	501	64	280
High	89	–	148
LSD ($P = 0.05$)	798	833	935
Heat index ($\times 10^3$)			
Low	522	429	425
Medium	391	205	250
High	64	–	102
LSD ($P = 0.05$)	266	277	226

burn in the stubble burning treatment was not hot enough for a sufficient time period to produce a total seed kill.

The extended duration of higher burning temperatures in the windrow treatment was due to the concentration of harvest residues (Fig. 2). There was $15\ t\ ha^{-1}$ of harvest residue concentrated in the conventional windrow treatment compared with the $2.3\ t\ ha^{-1}$ of residue in the standing stubble. The action of concentrating the harvest residue material including annual ryegrass seed and not using straw spreaders to redistribute this material across the field essentially increased the effectiveness of the burning treatment in killing ryegrass seed.

3.3. Narrow versus conventional windrow burning

When wheat stubble residues were concentrated in narrow or conventional windrows, soil surface temperatures during burning were hot enough and their duration sufficient to kill more than 96% of wild radish seed within pod segments placed on the soil beneath the stubble treatments (Fig. 4). In contrast only 10% of wild radish seed on the soil surface beneath the standing stubble treatment was destroyed by burning.

The concentration of harvest residues in the conventional and narrow windrows resulted in 4 and 6.7-fold increases in the

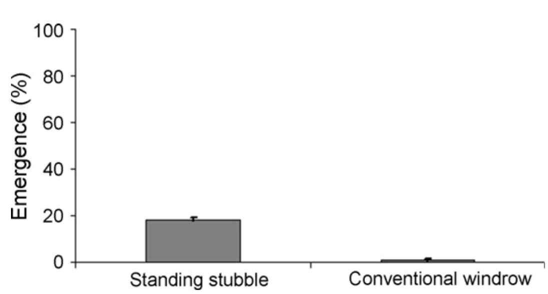

Fig. 3. Annual ryegrass emergence following burning of standing wheat stubble and conventional windrows at York in 2002. Bars represent standard error values for three replicates.

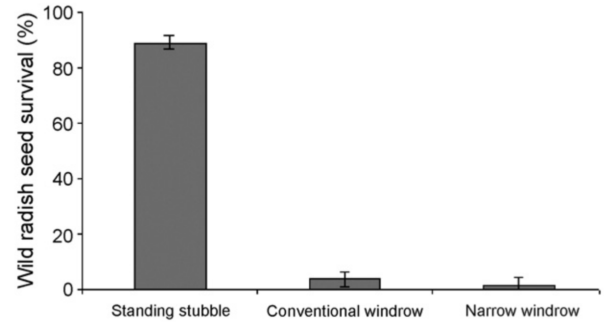

Fig. 4. Wild radish seed survival following burning of standing wheat stubble and narrow windrows at Konongorring in 2004. Bars represent standard error values for three replicates.

amount of biomass per unit area compared with the standing stubble treatment. Harvest residues are typically spread across the width of the swath (6–10 m) during the standard harvest operation. Therefore, the creation of conventional and narrow windrows during harvest means that residues are confined to less than 20 and 10%, respectively of the swath area. These are also the proportions of the field that are exposed to wind erosion when these windrows are subsequently burned. The concentration of residues in windrow treatments produced higher temperatures over a longer period during burning when compared with the standing stubble (Fig. 5), resulting in greater seed mortality. There was no difference in wild radish survival between these two windrow treatments (Fig. 4). This indicates that the level of stubble in the conventional windrow and subsequent burning intensity achieved was sufficient and that higher stubble levels and burning intensities were not needed.

3.4. Harvest residue level and narrow windrow burning

Increasing the amount of lupin harvest residue concentrated in a narrow windrow produced higher burning temperatures and increased the duration of the burning treatment. Higher amounts of lupin residue led to higher temperatures during burning as well as a longer duration of these higher temperatures (Fig. 6). There was a trend for higher maximum

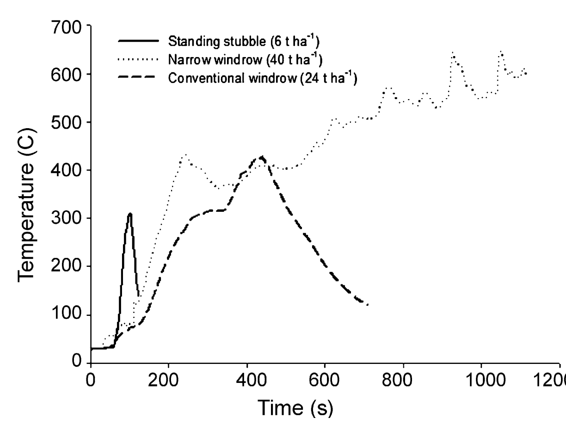

Fig. 5. Average temperatures recorded at 5 s intervals during burning of standing wheat stubble, stubble in a conventional windrow and a stubble in a concentrated windrow at Konongorring in 2004.

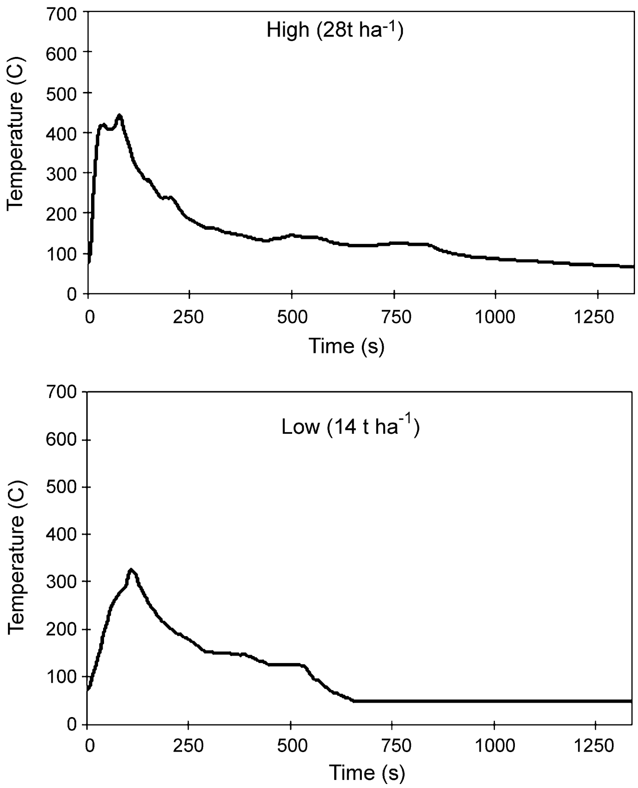

Fig. 6. Average temperatures recorded at 5 s intervals during burning of high and low levels of lupin harvest residue in narrow windrows at Mingenew in 2005.

temperatures, HI and EBT values in the high residue treatment, however, these differences were not significant (Table 3). Despite large differences between these parameters, in particular HI and EBT, variations in residue levels for the high (21–37 t ha^{-1}) and low (5–19 t ha^{-1}) residue level treatments resulted in highly variable data. Additionally, this variability prevented a clear trend for increasing HI values with higher lupin residue levels in narrow windrows ($r^2 = 0.16$) (Data not presented).

3.5. Wind speed and residue type effects on narrow windrow burning

Higher wind speeds during windrow burning increased the temperature of the burn but resulted in a quicker burning operation for lupin, wheat and canola stubbles. Wind speed effects were the same across all crop types where there was no effect ($P > 0.05$) of crop residue type on the maximum burning temperature, HI or burn duration (Table 4). Regardless of the type of residue in the narrow windrow the high wind speed treatment produced the highest burning temperatures and the shortest burning durations (Fig. 7). This also resulted in lower ($P < 0.05$) HI values for the high wind speed treatment for wheat and lupin harvest residues.

There appears to be less variation in burning temperature at the soil surface for high wind speeds compared to low wind speeds (Fig. 8). Burning during wind has the effect of feeding the fire with oxygen. Observations made during burning were

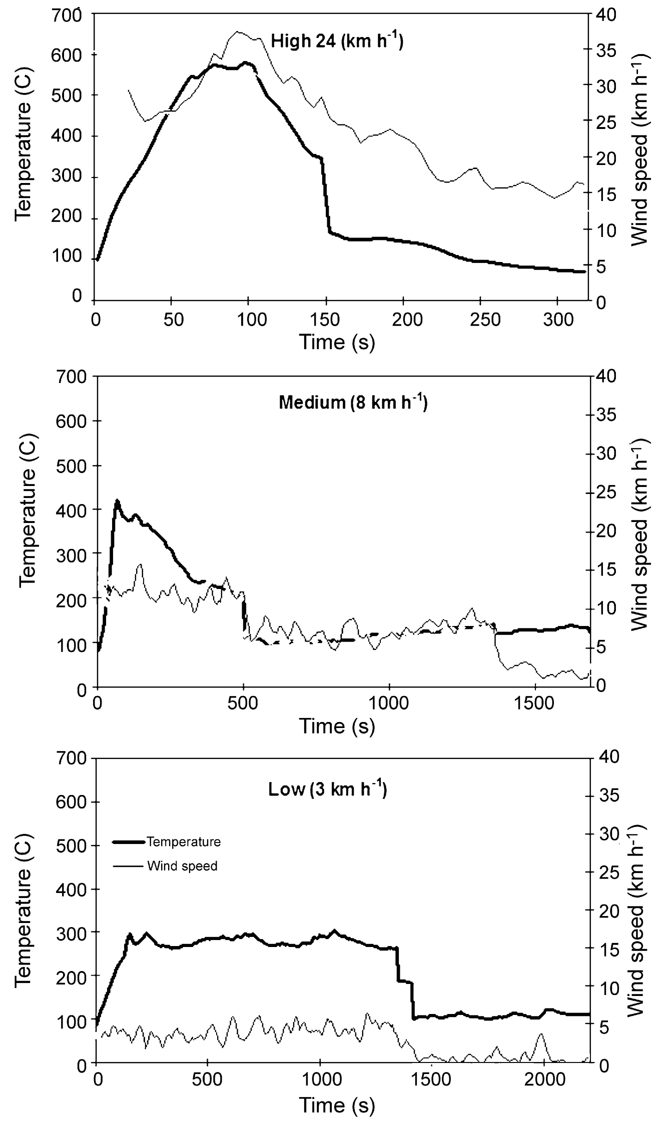

Fig. 7. Effect of wind speed on the average temperatures recorded at 5 s intervals during burning of stubble (average of lupin, wheat and canola stubbles) in narrow windrows at Mullewa in 2006.

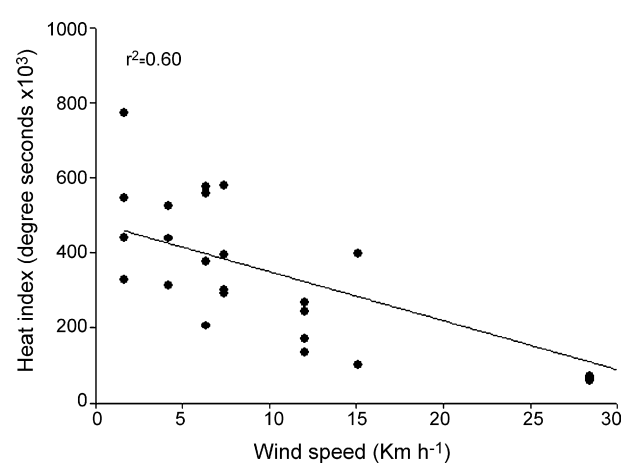

Fig. 8. Change in heat index with increasing wind speeds during burning of stubble in windrows of canola, lupins and wheat ($r^2 = 0.60$) at Mullewa in 2006.

that in some instances, in low wind conditions, the layer of burnt ash from the initial burn smothered the chaff below, reducing the ability of the windrow to burn to the soil surface. Wind blowing through this ash layer appeared to improve the burning of the chaff at the soil surface.

4. Conclusions

This study has established that burning windrows of harvest residues is an effective means of destroying wild radish and annual ryegrass seed. The temperatures achieved during windrow burning were found to be sufficient to destroy wild radish and annual ryegrass seed present on the soil surface. Burning standing stubble did not produce the same high temperatures for a prolonged period at the soil surface, reducing the potential for killing weed seeds. Burning standing stubble also has the disadvantage of exposing the soil surface, increasing the risk of erosion and is, therefore, not a recommended practice. Narrow windrows offer growers a number of benefits over conventional windrows including (i) reduced risk of erosion (<10% of the field is burnt, depending on harvester swath width), (ii) increased fuel levels in the windrow to achieve a longer, more reliable burn to the soil surface, (iii) improved reliability in burning wheat windrows without burning the whole field, (iv) narrow windrows suffer less from disturbance by grazing livestock. There are, however, some pitfalls with burning windrows that growers may face, including (i) summer rain reducing burning temperatures, (ii) low yielding crops producing insufficient biomass to attain a hot burn, (iii) the risk of burning the entire field leading to increased erosion potential and (iv) the redistribution of nutrients such as potassium into the windrow area and the loss of nutrients such as nitrogen and sulfur that are lost in smoke. With good management and attention to detail these pitfalls can be avoided. However, longer term options such as mechanical devices that destroy weed seeds as they exit the harvester are still desperately needed. In the mean time, windrow burning should be viewed as an effective means of removing weed seeds at harvest until a more attractive system is developed.

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