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 is used to concentrate harvest residues into narrow windrows for burning in the following autumn. This system enables the use of burning to destroy weed seeds while reducing the erosion potential associated with whole paddock stubble burning. The effectiveness of burning narrow windrows of wheat stubbles in killing annual ryegrass and wild radish seed was evaluated over four seasons in the northern wheatbelt region of Western Australia. Preliminary kiln studies determined that temperatures in excess of 400 ^{o}C for at least 10 sec was needed to guarantee the death of ryegrass seed while 500 ^{o}C for the same duration was required to kill wild radish seed within their pod segments. Temperature probes were used to record air temperatures at one to five second intervals on the soil surface beneath windrows during burning treatments. Burning standing stubbles was found to be the least effective in killing annual ryegrass and wild radish seed present on the soil surface. Burning temperatures beneath conventional and narrow windrows were consistently above 400 ^{o}C and for a sufficient period to expect that 100% of ryegrass and wild radish seed present on the soil surface beneath these windrows would have been destroyed. This was confirmed in several instances where annual ryegrass and wild radish seed placed beneath windrows prior to burning were no longer viable when recovered post-burning. Although burning exposes the soil surface increasing the potential for erosion the strategic burning of narrow windrows significantly reduces the erosion risk with generally less than 10% of paddock area being exposed by the burning of these windrows.

Key words
annual ryegrass, *Lolium rigidum Raphanus raphanistrum,* wild radish, windrow, burning.

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 (Reeves 1976; 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 (Rerkasem et al. 1980; Reeves et al. 1981). As both of these annual weed species rely on a large seedbank for persistence in cropping systems preventing inputs to the seedbank is an effective means of reducing the impact of these weeds on subsequent crops. Reduced capacity for herbicidal control due to the widespread evolution of herbicide resistance in annual ryegrass (Owen et al. 2005) and wild radish (Walsh et al. 2005) makes it important to prevent the input of seed from these species into the seedbank.

Several techniques have been developed to target mature weed seeds at the end of the growing season. A number of systems have been developed allowing the collection and removal or destruction of the weed seed containing fraction of the harvest residue. Both annual ryegrass and wild radish seed exit the harvest in the chaff fraction during harvest and the collection of this material in “chaff carts” facilitates the removal of 75 to 85% of ryegrass seed and 70 to 80% of wild radish seed that enters the harvester (Walsh and Parker 2002). The baling of harvest residues is also practiced by some producers primarily for the purpose of generating income from the baled material but also for the collection of weed seeds. Baling harvest residues collected from the soil surface or directly from the rear of the harvester has been shown to allow the collection of 50 and 95% respectively of ryegrass seed entering the harvester (Unpublished data). Despite these results, chaff carts and baling systems are not widely used by Western Australian grain growers due to a number of limitations including reduced harvest capacity, machinery break downs and capital costs. For these reasons, a small number of growers began using the practice of burning narrow windrows in 2001. These farmers used a chute mounted to the rear of the harvester to concentrate all of the straw and weed seed bearing chaff residue into a narrow (700 mm wide) windrow. These windrows are 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 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 all weed seeds present, then similar levels of weed seed control can be expected from burning narrow windrows as chaff collection in a trailing cart or baling residue directly from the harvester. 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. To establish the potential of this practice kiln studies were conducted to determine the temperature requirements for destroying ryegrass and wild radish seed. These were then followed with field studies aimed at determining the temperatures achieved during the burning of standing wheat stubbles and narrow stubble windrows. The effect of these burning treatments on the subsequent seedling establishment of annual ryegrass and wild radish was also investigated.

Materials & Methods

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 seed (Table 1) and wild radish seed within their pod segments (Table 2) were placed in porcelain vessels that were then placed in a kiln, at pre-determined temperatures and for specific periods of time. Three 100 seed lots of each species were exposed to each combination of temperature and duration.

Following removal from the kiln, annual ryegrass seed and wild radish pod segments were allowed to cool to room temperature. Wild radish pod segments were carefully dissected to remove the seed. Wild radish and annual ryegrass seed were then placed on 1% (w/v) water based agar in petri dishes. All dishes were surrounded by parafilm to ensure that the agar didn’t dry out. Petri dishes were placed in an incubator for 14 days and were exposed to alternating temperatures (day/night) of 25/15^{o}C and a 12hr photoperiod. After this period annual ryegrass and wild radish seeds were classified as viable if they had germinated or remained firm and free of infection.

Standing stubble versus conventional windrows

Investigations on the effects of burning windrows and the standing stubble on annual ryegrass seed were conducted at York (31^{o}95`S, 116$^{o}$89`E) in autumn in 2003. The wheat crop used to establish the stubble treatments was uniform and yielded 1.9 t/ha of grain and 2.3 t/ha of above-ground dry matter. An annual ryegrass free site was chosen and viable, non-dormant annual ryegrass seed were added to the stubble treatments by pouring seed into the front of the header during the harvest. Standing and windrowed stubble treatments were established during the harvest of the wheat crop. The conventional stubble windrow was created by letting the straw and chaff material drop onto the ground out of the back of the harvester creating a windrow that was 1.2m wide. 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 header. Post harvest residue sampling across the stubble treatment plots was conducted to determine the stubble biomass levels and ryegrass seed numbers present on the soil surface. Six chaff samples were collected at harvest and after sieving these samples, it was determined that there were approximately 1600 seeds/m^2 of annual ryegrass exiting the harvester in the chaff fraction in the windrow treatment as compared to approximately 200 seed/m^2 in the standing stubble treatment.

Recording temperatures during harvest residue burning.
Burning treatments were conducted on the 15th April 2002. Prior to burning the thermocouples were located at four heights within the windrow and standing stubble treatments, 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-second 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 on or above the soil surface to record the temperature and duration of the burning treatments.

A season commencing rainfall event occurred over the 16-18th April period, with 17 mm recorded at the site. Counts of emerged annual ryegrass seedlings were conducted two weeks later where the number of seedlings in a 0.25 m^2 quadrat was determined at 9 locations in each strip. Stubble plots were established in randomized complete block design with six replicates.

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 stubble at Konnongorring (31°03`S, 116°47`E 31). Narrow windrows were created by mounting a chute to the rear of the harvester that concentrated the harvest residues into a narrow windrow as it exited the harvester. This created a windrow that was 600mm to 700mm wide. Narrow windrows, therefore, were approximately half as wide as conventional windrows that were created simply by removing straw spreaders / choppers and allowing harvest residues to fall to the soil surface. Consequently, the biomass in a narrow windrow is approximately double that of conventional windrows.
Temperatures were recorded at three heights within the windrow and standing stubble treatments as decribed above. Burning of stubble treatments was conducted on 24th March in mid-afternoon during the warmest part of the day.

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 area of stubble or length of windrow. In the harvest residue type and residue level experiments 1.0 m windrow lengths of each windrow treatment were sampled just prior to burning. Temperature probes were placed in residue sections adjacent to where residue samples were taken. Due to the variations in temperature and exposure times for each treatment, a heat index was used. The heat index (HI) was derived by summing the temperature above ambient achieved for the time of the burn. This figure reflects the intensity of the burn, encompassing both temperature and duration. Effective burning time (EBT) was determined as the time in seconds when the burning temperature was above 300 ^{o}C and was calculated for each burning treatment. An analysis of variance was performed on HI, EBT, and maximum temperature values recorded during burning treatment using Genstat. Means were separated using Tukeys HSD where p=0.05.

Results and Discussion

Kiln experiment.
It was identified that 400°C was required to kill annual ryegrass seed following the shortest exposure of 10 seconds. At lower temperatures longer exposure periods were required to kill 100% of annual ryegrass seed. For instance at 300°C more than 20 seconds was required while at 250°C a 60 second exposure period was needed. Wild radish seed within their pod segments were more resilient to higher temperatures than ryegrass where a temperature of 500°C was required to kill all wild radish seed during a 10 second exposure period (Table 1).

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

(A) Annual ryegrass	Temperature (^oC)					
Duration (seconds)	200	225	250	275	300	400
	% Survival					
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
	Temperature (^oC)					
(B) Wild radish	300	350	400	450	500	
Duration (seconds)	% Survival					
10	89	88	85	22	0	
20	89	67	1	0	0	
60	1	1	0	0	0	

To relate temperature and exposure period in the kiln experiment to seed mortality a heat index (HI) was derived as the summation of temperatures in degrees Celsius for each second during the exposure period. The relationship between HI and seed mortality provided good correlations for annual ryegrass (r^2 = 0.72) and wild radish (r^2 = 0.90) respectively (Figure 1). Therefore, HI values were calculated in subsequent burning treatments and used to indicate the potential efficacy of these treatments in controlling annual ryegrass and wild radish seed.

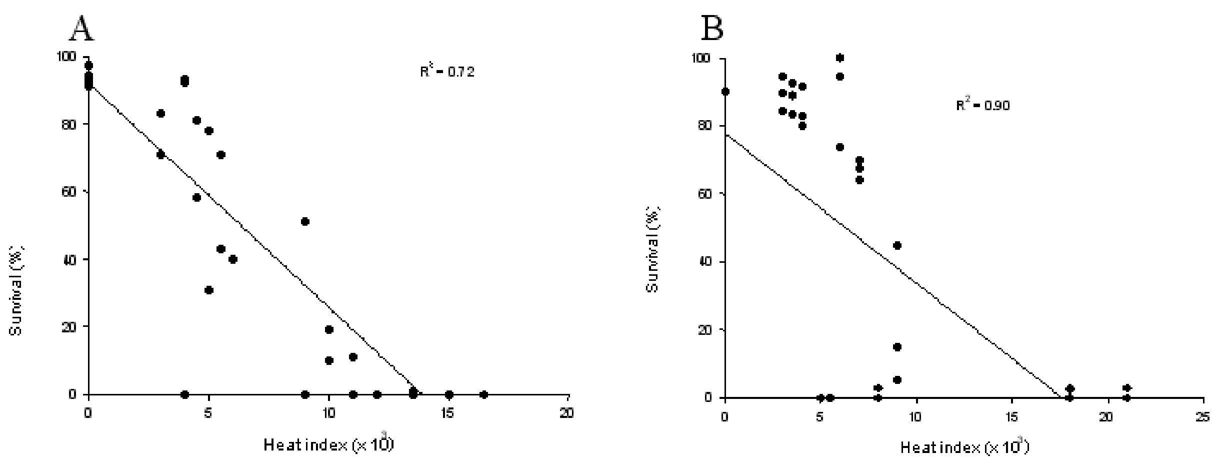


Figure 1. Effect of heat index (HI) on the seed mortality of *L. rigidum* (A) and *R. raphanistrum* (B) as determined by the kiln experiment.

Standing stubble versus windrow stubble burning

Temperatures recorded during burning of the conventional windrow treatment were much higher and the duration of the burn was substantially longer than for the standing stubble treatment. The 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 (Figure 2, Table 2).

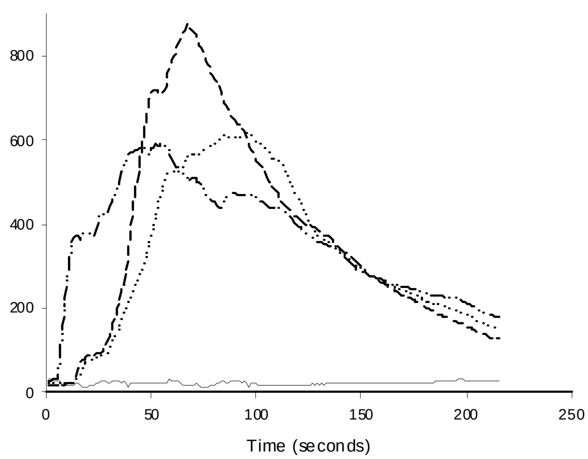
High temperatures recorded during the windrow burning treatment persisted for up to four times longer than in the standing stubble treatment (Figure 2). Elevated temperatures were still occurring 200 seconds after the windrow started burning. In contrast the temperature was almost back to the ambient level in just over 50 seconds in the standing stubble treatment.

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

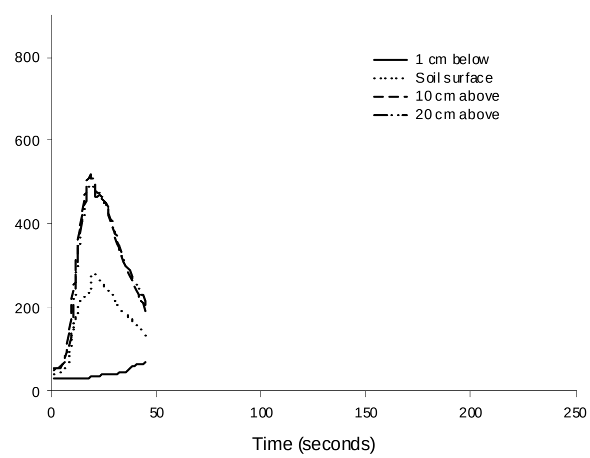
Stubble treatment	Maximum Temperature (°C)	Heat Index (x 10^3)	EBT (seconds)
Standing	406.3	10.5	19
Conventional windrow	555.3	30.6	68
LSD (P=0.05)	232.7	2.7	16.2

In the windrow treatment all above ground temperature recordings were high enough to have resulted in the death of annual ryegrass seed. Therefore, any ryegrass seed, located above the soil surface, within the windrow, would have been destroyed during the burning of the conventional windrow. In comparison it was only at the 10 and 20 cm heights in the standing stubble treatment that complete annual ryegrass seed kill is likely to have occurred.

The temperatures recorded at the soil surface indicate that burning standing stubbles has a reduced potential for killing weed seeds than burning windrowed stubble. In March annual ryegrass seed are typically only found on the soil surface (Davidson 1994) in wheat stubble paddocks, 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 produced a significantly higher HI value compared to that of the standing stubble treatment (Table 2). In other words the hotter and longer burn of the windrow treatment resulted in higher temperatures being recorded at the soil surface for a longer period in this treatment compared with the standing stubble treatment. As higher HI values indicate an increased chance of seed mortality (Figure 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.



(A)



(B)

Figure 2. Temperatures recorded at four heights during burning of a conventional windrow (A) and standing stubble (B).

Windrow burning was more effective than standing stubble burning in reducing annual ryegrass seedling emergence at the start of the growing season. Only 1.0% of the ryegrass seed that was placed in the windrow at harvest subsequently emerged as seedlings after the burning treatment the following autumn (Figure 3). In contrast the ryegrass counts in the standing stubble burning treatment revealed that 20 % of the ryegrass seed persisted through summer and 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 indicate that the burn was not hot enough for the required time to give a total seed kill in the standing stubble burning treatment.

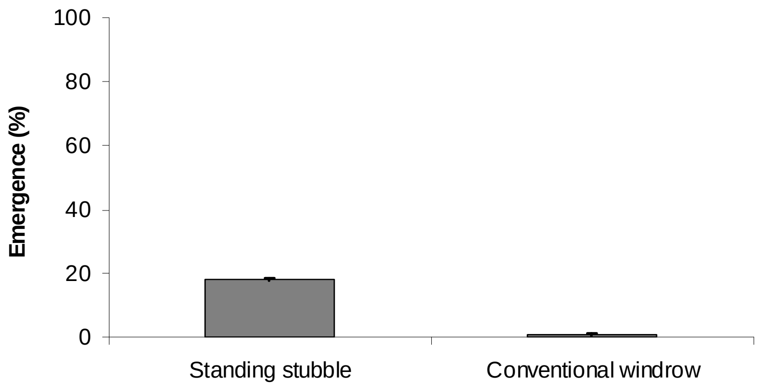


Figure 3. Annual ryegrass emergence following burning of standing wheat stubble and conventional windrows at York in 2004. Bars represent standard error values for three replicates.

The extended duration of higher burning temperatures in the windrow treatment was due to the concentration of harvest residues (Figure 2). There was 15 t/ha of harvest residue concentrated in the conventional windrow treatment compared with the 2.3 t/ha of residue in the standing stubble treatment. Therefore, by not spreading the harvest residue and allowing it to fall into a windrow at the back of header during harvest there is a concentration of fuel available for burning. As annual ryegrass and wild radish seed primarily exit the header in the harvest residue (Walsh and Parker 2002) they are concentrated along with the straw and chaff residues in the formation of a conventional windrow. The action of concentrating the harvest residue material including annual ryegrass seed and not using straw spreaders to redistribute this material across the paddock increased the effectiveness of the burning treatment.

Narrow versus conventional windrow burning

When wheat stubble residues were concentrated in narrow or conventional windrows soil surface temperatures during stubble burning were hot enough for a sufficient period of time to kill the majority of wild radish seed present on the soil (Figure 5).

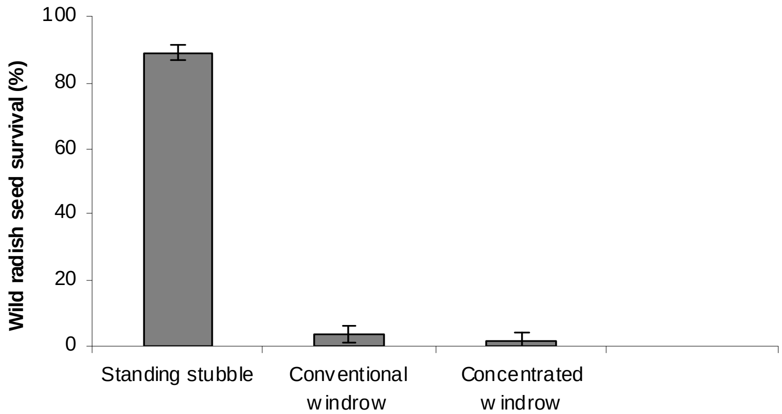


Figure 4: Wild radish seed survival following burning of standing wheat stubble and conventional and narrow windrows at Konongorring in 2004. Bars represent standard error values for three replicates

Burning conventional and concentrated windrows was equally effective in controlling wild radish seed present on the soil surface beneath these windrows. More than 96% of wild radish seed within pod segments placed on the soil surface beneath the stubble treatments immediately prior to burning were destroyed during the burning of the windrow treatments (Figure 4). In contrast only 10% of the wild radish seed on the soil surface in the standing stubble treatment were destroyed by stubble burning. These differences in wild radish seed viability are likely to be due to the differences in the heat intensity of the burning treatments.

The conventional and narrow windrow treatments burnt at higher temperatures over a much longer period than the standing stubble (Figure 5). As was observed earlier with annual ryegrass, concentrating harvest residues or fuel source into a windrow produced a much higher seed mortality of wild radish because of the higher burning intensity. The concentration of harvest residues in the conventional and narrow windrows resulted in 4 and 6.7 fold increases in the amount of biomass per unit area compared with the standing stubble treatment. However, there was 16 t/ha more biomass in the narrow windrow compared to the conventional windrow. This resulted in a much higher burning intensity in the narrow windrow treatment compared to the conventional windrow. However, there was no difference in wild radish survival between these two treatments. This indicates that the level of stubble in the conventional windrow and subsequent burning intensity achieved treatment was adequate and higher stubble levels and burning intensities will not provide additional weed seed destruction.

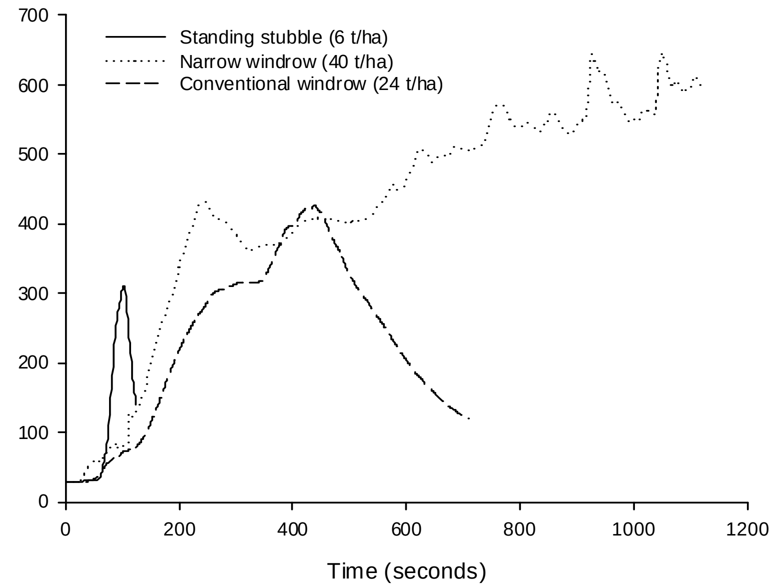


Figure 5: Temperatures recorded during burning of standing wheat stubble, stubble in a conventional windrow and a stubble in a concentrated windrow at Konongorring in 2004.

Conclusions

Burning windrows has been shown in these studies to be an effective means of destroying wild radish and annual ryegrass seed preventing their subsequent germination within cropping phases. The temperatures achieved during windrow burning are sufficient to destroy wild radish and annual ryegrass seed present on the soil surface. Burning standing stubble does not produce these same high temperatures for a prolonged period at the soil surface reducing the potential for killing weed seeds. Burning standing stubble also increases the risk of wind erosion and is, therefore, not a recommended practice. Narrow windrows offer growers a number of benefits over conventional windrows including (i) reduced risk of wind erosion (only 5% to 7% of the paddock is burnt); (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 paddock; (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 paddock leading to wind erosion issues and (iv) the redistribution of nutrients such as potassium into the windrow area and the loss of nutrients such as nitrogen and sulfur that go up 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 but temporary means of removing weed seeds at harvest until a more sustainable system is developed.

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