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Wildfire Behavior and Ember Generation of Dryland Wheat

Abstract

Farmers are increasingly dealing with wildfires burning in wheat and other dryland (non-irrigated) crops due to increased crop residue from no till farming practices and additional human ignitions from sources other than farming. Fire managers and wheat farmers want to better understand fire behavior of dryland wheat to inform fuels management and fuel break construction. Fuel breaks can be an important tool to break up continuous fuel to improve firefighter safety and suppression effectiveness. However, there is limited research on flame height and ember generation to support the ideal width of fuel breaks near wheat fields. The goal of this study was to quantify fire behavior in wheat to better inform farmers and fire managers on the ideal width of fuel breaks and expected fire behavior. Unharvested dryland wheat was collected and burned in controlled experimental burns under fire season conditions in August 2022 in North Central Oregon to determine flame height, time to ignition, duration of combustion, ember generation, and distance of ember travel. Six different small scale burn tests were completed with an average flame height of 11.0 ft with a maximum height of 14.5 ft. On average time to ignition was 3.7 seconds and duration of combustion was 113 seconds for 20.5 sq ft of wheat. On average 110 embers were produced from 13 lbs of wheat with most embers travelling 3.0 ft with a maximum distance of 7.3 ft. Ember generation and flame height suggest that fuel breaks need to be at least 45 ft wide to aid in fire suppression efforts and likely need to be considerably wider under windy conditions or in steep terrain.

Introduction

Wildfires have increased in size and frequency across rangelands and croplands in Western North America over recent decades (Brooks et al., 2004; Shinneman et al., 2018). In 2018 nearly 120,000 acres of dryland wheat, pastures, and rangeland burned in North Central Oregon. Increasingly pastures, vineyards, and other agricultural crops are also being impacted by wildfires in California (California State Assembly Committee, 2020). The increase in the frequency and size of wildfires in agricultural areas is due to several factors, including increasing human starts from vehicles along roadways and heavy continuous fuel loads of annual grasses. Farmers are also leaving more crop residue on the soil surface to decrease soil and water erosion which is increasing fuel loads that can contribute to wildfire spread.

Cereal grain crops are large continuous monoculture crops that cover much of eastern Oregon and occur throughout the world. Across Oregon, Washington, and Idaho over 4.2 million acres of wheat are harvested each year valued at $2.1 billion (Hagerty et al., 2023). Most row crop producers in the United States now use no till farming practices where residue from previous crops is left standing and the next crop seeded through it. This has dramatically reduced soil erosion from water and wind but has placed more fuel across the landscape to contribute to wildfire spread (Personnel obs.). Fuel models used by wildland firefighting professionals in the United States list agricultural fuels as non-burnable (NWCG 2025). However, dryland crops (crops that are not irrigated) burn readily once they are fully mature and about to be harvested, typically during the peak of fire season. In addition, because dryland wheat is not irrigated it dries out earlier than other irrigated crops. Wheat forms a dry and continuous fuel that can easily catch on fire during harvest operations or from other human ignition sources. Due to the size of wheat production in the Western United States and challenges with suppressing wildfires in wheatfields there is an increased interest and need for fuel breaks.

Fuel breaks can decrease the frequency and size of wildfires by breaking up fuel continuity. In addition, fuel breaks provide firefighters with safe areas to engage wildfires where rates of fire spread and flame lengths are reduced (Maestas et al., 2016). Fuels are typically modified in fuel breaks by being removed or reduced through herbicides, mowing, or targeted grazing. In agricultural areas disking has been used for the last several decades as one way to create fuel breaks around crop fields. Fuels can also be modified by seeding perennial vegetation to create vegetative fuel breaks. Studies have shown that fuel breaks can be effective, assuming there is firefighter access to them. One study in California found that fires stopped at fuel breaks 46% of the time, primarily where firefighters had good access (Syphard, Keeley, & Brennan, 2011). However, there is limited fire behavior research to determine ideal widths of fuel breaks adjacent to dryland wheat fields.

Wildfires in ripe unharvested wheat can be challenging to contain due to intense heat, long flame lengths, and ember propagation. Wheat is a unique fuel type with limited fire behavior research completed. However, recent fire activity in Australia has prompted fire behavior research to better inform wildland firefighters and farmers (Cruz et al., 2020). Research in Australia found that unharvested wheat can generate average flame heights of 11.8 ft ranging from 9 ft to 16 ft and travel an average of 4.5 miles per hour (Cruz et al., 2020). Fire behavior was significantly reduced once wheat was harvested (Cruz et al., 2020).

Similar to shrubs and trees, burning unharvested wheat can release embers that can travel and start additional fires where they land. Wheat releases embers as wheat heads or spikes become detached from the stalk while they are burning (Personnel obs. and discussions with local farmers). These burning kernels then become lofted in the wind and can cause spot fires across fuel breaks and fire breaks. No research has been completed on the length that wheat embers can travel or how many embers are generated from a burning field. Previous research has quantified ember generation from trees and shrubs using small experimental burns with strategically placed fire-resistant fabric that hot embers leave scorch marks on (Adusumilli, Chaplen, et al., 2021; Adusumilli, Hudson, et al., 2021). A single tree or shrub is placed at a center location and ignited. Frames with special fire resistant fabric are placed strategically around the burning fuel to capture any embers that are generated. The fabric will leave a scorch mark if the ember is hot enough to propagate wildfire spread. This allows for hot embers to be distinguished from other embers that are not hot enough to contribute to wildfire spread.

The objectives of this study are to determine the distance that embers can travel, how many embers are generated, flame height, time to ignition, and duration of combustion for mature unharvested wheat. The goal of this research is to better inform farmers and fire managers on the ideal width of fuel breaks and expected fire behavior.

Materials and Methods

Study location

Unharvested mature wheat (soft white wheat variety VI VooDoo) was pulled up by the roots in a field at the Sherman Experiment Station in Moro, OR and then transported the same day as the burn tests to Mid Columbia Fire and Rescue in The Dalles, OR. Fuel moisture was determined for a subsample of wheat from each burn test by weighing samples at time of collection and several days later after samples were air dried to a consistent weight. All samples were taken from the same field within 48 hours to minimize potential variability in fuel moisture.

Experimental burn set up

Burn tests were completed at Mid Columbia Fire and Rescue in The Dalles, OR in their training parking lot. All burns were conducted under the approval and supervision of Mid Columbia Fire and Rescue. In each burn test wheat was spaced into three different rows using bricks (15.5 inches long by 7.625 inches wide) and arranged to match row spacing commonly used in wheat production in the region. Four rows of bricks were used to hold the wheat in place. Each row was 6.5 ft long for a total surface area of wheat burned of 20.5 sq ft. The amount of wheat burned was weighed before each test. An average of 13 lbs of wheat was burned in each burn. Wheat was consistently at a height of 45 inches when placed in between the brick rows. A total of six replicates were burned over the course of two different days in August 2025. Burns were started by placing several matches at the base of the wheat on the north side. A light consistent breeze from the north pushed flames from the north end through the rest of the wheat in each test.

Burns were conducted intentionally on days with low humidity and high temperatures to increase fire behavior and test under realistic conditions. Burns were also conducted under consistent calm winds to maintain consistency between tests. Weather conditions during burn tests were relatively consistent with low relative humidity, little wind, and high temperatures (Table 1). Relative humidity, wind, and temperature were monitored during burn tests using a Kestrel 5500FW Fire Weather Meter Pro.

Table 1. Relative humidity and temperature onsite during each burn test in 2022.

Burn Date	Relative Humidity (%)	Temperature (°F)	Wind (mph)
08/24/2022	25	100	3
08/24/2022	22	101	5
08/24/2022	25	100.3	6
08/24/2022	24	100	2
08/25/2022	35.8	90	4
08/25/2022	19	95.5	3

Data collection

Each burn test was filmed using a Canon EOS M50 camera stationed at a consistent location and distance from the burn test. A steel pole measuring ten ft was set up adjacent to the burn tests to help quantify flame height with markings placed every six inches. A digital watch was used to determine the time to ignition (time in seconds for the sample to sustain a flame for more than one second) and duration of combustion (how long the sample burned i.e. elapsed time from ignition to extinction). Flame height was estimated in the field and then verified using burn test videos and Camtasia video software with a measured grid system. Similar methods were used to quantity embers as by Adusumilli, Hudson, et al., 2021. Frames were placed next to each other without any gaps within a semicircle around the burn with in 12 ft (Figure 1.). Frames were placed one ft back from the edge of the burn after initial tests revealed that it was impossible to distinguish embers from scorch marks cause by the heat of the burn.

Initial tests indicated that under calm winds hot embers did not travel further than 12 ft and thus frames were not placed past 12 ft from the burn. After each burn test the scorch marks were measured and counted.

Figure 1. Experimental burn set up with dryland wheat and fire resistant fabric to quantify ember generation and flame height.

Statistical Analysis

Linear regressions were used to test for any correlation between flame height, ember distance, and total numbers of embers with wind speed, relative humidity, and temperature. Statistical analyses were conducted using the computer software program R (R Core Team, 2024). All figures show original, non-transformed data.

Results

An average of 110 wheat embers were generated during the study from an average of 13 lbs of wheat per burn test. Wheat biomass was consumed completely during each burn. There was an average of 8.5 embers generated per pound of wheat. On a per area basis an average of 5 embers per sq ft were generated. Most wheat embers travelled 2.0 to 3.0 ft away from the fire front, but a few embers made it 7.3 ft away (Figure 2). There was no significant influence of wind, temperature, or relative humidity on the number of embers generated, distance traveled, or flame height. The longest flame height during the experimental burn was 14.5 ft and averaged 11 ft. The average time to ignition was 3.7 seconds with duration of combustion lasting an average of 113 seconds. Fuel moisture averaged 6.11% with a standard deviation of 0.75%.

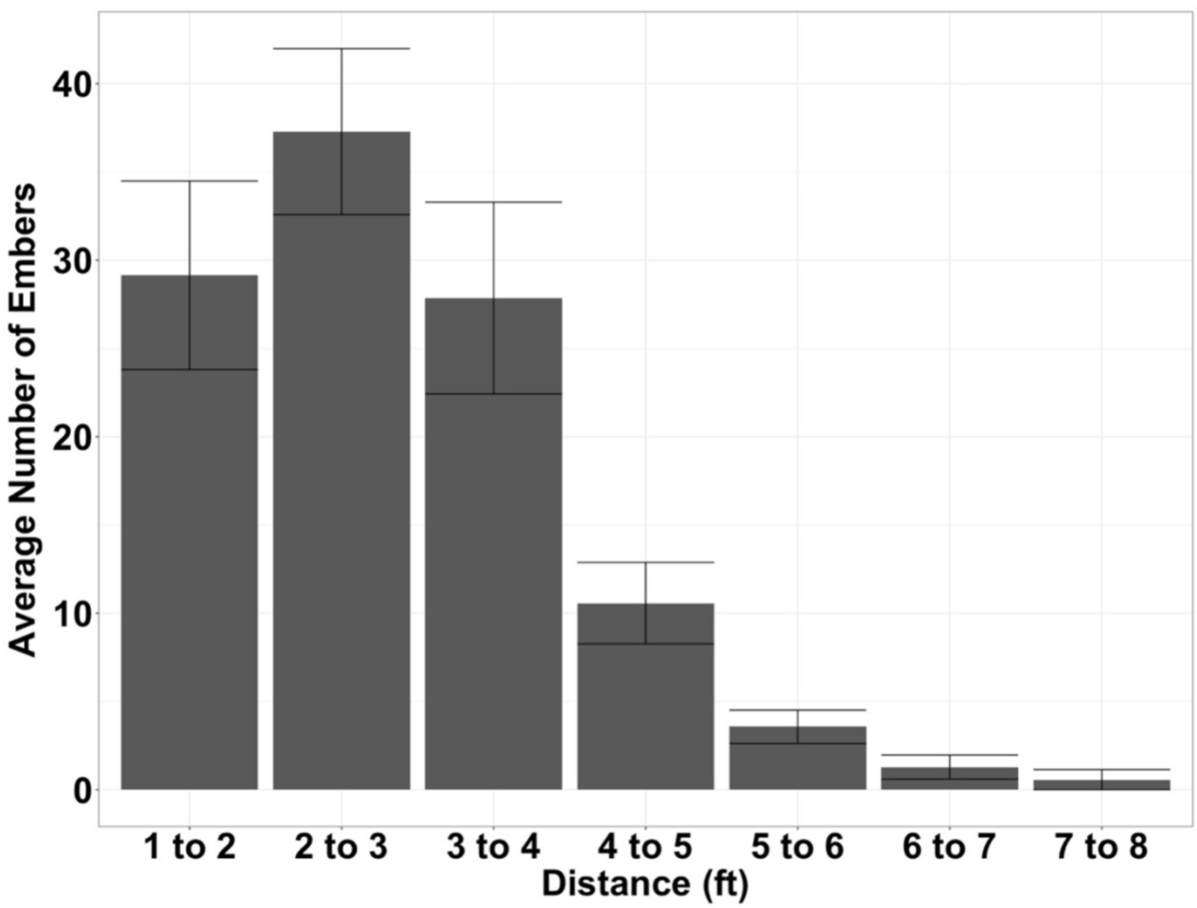

Figure 2. Average number of wheat embers in one ft increments away from experimental burn front from six different experimental burns in August 2022. Error bars represent one standard error.

Discussion

Burn characteristics clearly showed that wheat at the mature crop stage with a low fuel moisture of 6% was easy to ignite. Wheat only needed an average of 3.7 seconds to ignite. In an average of 113 seconds the entire 20.5 sq ft of wheat was burned. Overall embers did not travel further than 7.3 ft from the fire front, but under windier conditions embers likely would travel further and pose more of a threat to wildfire spread. Most embers travelled 2.0 to 3.0 ft from the burn. With an average of 37 embers this would pose a major control problem if a fuel break was not present in front of the fire. The wheat was 45 inches tall and taller wheat varieties would likely generate more embers. In addition, the wheat variety VI Voodoo is a bearded or awned variety, which may increase the embers generated compared to awn-less varieties that have less fuel to burn on each spike. Most wheat varieties used in the region continue to have awns to deter grazing by deer and elk.

Compared to similar studies on trees and shrubs the number of embers generated by wheat are quite small. Sagebrush can generate 340 to 1,680 embers per lb of consumed biomass (Adusumilli, Chaplen, et al., 2021). However, sagebrush is a taller plant than wheat and has a unique chemical composition that increases fire behavior compared to unharvested wheat. Douglas fir and ponderosa pine generate less embers than sagebrush, but still more than wheat with an average 114 to 340 embers per lb of consumed fuel (Adusumilli, Chaplen, et al., 2021). While wheat does generate embers, this research indicates that it is less of a concern than sagebrush or tree species commonly burning during wildfires in the region. However, it only takes a few embers for a fire to spread when considering how easily wheat and surrounding rangeland vegetation can ignite.

While embers only traveled a max distance of 88 inches or 7.3 ft, flame height was much further. The average flame height was 11 ft with a maximum distance of 14.5 ft. Considering the wheat burned in this study was only 45 inches tall it is impressive how tall the flame height was. Flames were nearly triple the height of the wheat fuel being consumed. Flame heights in this study were similar to results found with larger scale experimental burns in Australia that found an average flame height of 11.8 ft (Cruz et al., 2020). Average flame heights in this study were slightly shorter and the maximum flame height of 14.5 ft was also shorter than the 16 ft flame length found by Cruz et al., 2020. There may be scale factor that our study had less wheat to get to a critical mass, but overall results are similar suggesting that ember generation rates would likely be similar if larger scale field burns were conducted. Wheat may appear to be a grass fuel type, but the flame height, fire intensity, and ability to generate hot embers from unharvested wheat suggests it is closer to a shrub or brush fuel model.

Fuel breaks are meant to slow down the rate of fire spread and create safe zones for firefighters to engage the fire. A rule of thumb for fuel break widths in the past has been for it to be two to three times as wide as the expected flame height or length (Bennett 2017). This means that suggested fuel breaks adjacent to wheat should be a minimum of 30 ft to 50 ft wide given maximum flame heights of 14.5 ft in this study and 16 ft by Cruz et al., 2020. However, given that fuel breaks are meant to create safe zones for firefighters the width likely needs to be doubled to 100 ft wide to ensure firefighter safety under extreme conditions. In addition, fire behavior is increased on steep ground and recommendations would need to be increased. Other research in forested environments suggest a minimum fuel break width of 230 ft for 60% slopes (Bennett 2017).

These results should be used with caution as the study was completed under calm winds on flat ground. Flame heights and distance of ember travel could be significantly further under windy conditions. There may also be more embers produced per mass of wheat across a larger field where there is more fuel to contribute to greater fire intensity. This study also occurred during only one year during a narrow set of days during the fire season and results would likely show more variability if completed at other dates during the fire season. Additional research is needed to continue to fill the void on fire behavior in dryland wheat to better predict fire behavior and minimize damage to property, crop production, and safety for both firefighters and farmers.

Conclusion

While wheat produces fewer embers than shrubs and trees, it still generates enough embers to create challenges during wildfire suppression. Embers did not travel that far under calm winds, but likely would travel farther under windier conditions. Flame height is likely a larger concern for fuel break construction and fire management than embers with flame heights reaching 14.5 ft. This research suggests that fuel breaks should be a minimum of 50 ft wide in dryland wheat and doubled in steep terrain or where extremely gusty winds may occur. Depending on what resources fuel breaks are being used to protect a considerably wider fuel break would also be justified. Additional research is needed to quantify fire behavior of wheat and other flammable dryland crops that pose challenges for farmers and firefighters.

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