Straw Management and Crop Rotation Alternatives to Burning Wheat Stubble: Assessing Economic and Environmental Trade-offs

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Title: Final Report for Straw Management and Crop Rotation Alternatives to Burning Wheat Stubble: Assessing Economic and Environmental Trade-offs

Submitted to: Agricultural Burning Practices and Research Task Force

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Proposal Summary and Key Findings

Farmer incentives for burning wheat residues include: (1) facilitating the establishment of the next crop; (2) decreasing incidence of soil-borne disease; (3) decreasing nutrient (e.g. N) tie-up by decomposing cereal residues; and (4) positive response of crop growth, yield and economic return. On the other hand, potential disincentives of residue burning to growers can be difficult to quantify, particularly in the short-term, and include negative impacts on overall soil organic matter levels, loss of nutrients (e.g. N, P and S), and increased hazard of soil erosion if burning is combined with too much tillage. In order for growers and policy makers to base decisions on sound science, trade-offs among economic and environmental factors associated with field burning must be quantitatively assessed. Unfortunately, assessing these trade-offs has largely been based on assumptions that may or may not be valid including: (1) the quantities of residues and associated nutrients (eg. N, P, S) actually lost from a field via burning; (2) field burning impacts on labile soil organic matter constituents that effect crop nutrient availability (e.g. N, P, S); and (3) soil-borne disease or straw toxicity effects. To make matters more complicated, field-scale variation in these and other factors suggests that evaluating these economic and environmental trade-offs likely has a strong site-specific component. Our overall goal is to build on past research conducted on crop rotation and residue management alternatives to burning while strengthening the scientific knowledge surrounding actual field burning effects on residue C and nutrient losses, nutrient supplies, soil-borne disease, crop

performance and associated economics. Specifically our objectives are to: (1) document and economically assess wheat residue burning effects on soil organic matter, site-specific soil erosion estimates, soil condition (SCI), and residue C and nutrient (N, P, S) losses; (2) identify and economically assess crop rotations and sequences that benefit from retaining winter wheat residues in direct-seed systems; (3) document effects of wheat straw management and rotation alternatives on root pathogens; and (4) convey project findings through electronic and print media, field days, conferences and research site tours.

All studies were conducted at the WSU Cook Agronomy Farm (CAF) within the 140 acres that have been managed using continuous direct-seeding since 1999. We found that:

1. Fall burning reduced surface winter wheat residue mass by 62% whereas spring burning reduced residue mass by 55%.
2. Overall, 2,010 lbs C/ac were lost from fall burning while 1,271 lbs C/ac were lost during the spring burn.
3. The average amount of N lost by burning was similar with 12 lbs N/ac lost during the fall burn and 11 lbs N/ac lost during the spring burn.
4. Winter wheat residue N lost during the spring burn was 40% and for fall burn 33% of total; N losses from burning were appreciably lower than the previously reported losses of nearly 100% reported from laboratory studies of residue burning.
5. Losses of K, P and S from fall burning averaged 27.4, 1.0 and 2.6 lbs/ac, respectively. Losses of K, P and S from spring burning were less than what occurred in the fall averaging 3.8, 0.7 and 1.1 lbs/ac, respectively.
6. Average fertilizer replacement costs for nutrient loss during fall burning were $28.62/ac and nearly three times greater than for spring burning ($9.64/ac).
7. Residue burning had little impact on the following soil properties: soil N%, soil C%, soil C/N ratio, bulk density, soil pH and particulate organic matter (POM) C/N ratio, for this one year study.
8. Fall burning of winter wheat residue increased early season (wheat tillering stage) soil N availability, spring wheat growth and development and spring wheat N uptake as compared to controls with no burning.
9. Aboveground spring wheat N uptake at early stage (tillering) was 112% greater in fall burned as compared to control plots.
10. Field deployed PRS probes had 40% more µg N 10 cm^{-2} 7 $days^{-1}$ in fall burned as compared to control plots. The relationship between plant N uptake and the PRS probe data was linear and highly significant.
11. Winter wheat, spring wheat and spring chickpea yields following a winter wheat crop were not significantly different between fall burn and control treatments. In contrast, spring barley yields were 11% greater following fall burning as compared to controls (no burning). The excellent yields of spring garbonzo beans following winter wheat identify this crop as a rotational alternative under direct seeding.
12. In spring wheat, less Fusarium Crown Rot occurred in treatments with burning, and higher disease occurred with N fertilizer.

Project Objectives and Deliverables:

Objective 1: Document and economically assess wheat residue burning effects on soil organic matter, site-specific soil erosion estimates, soil condition index (SCI), and residue C and nutrient (N, P, S) losses. Cook Agronomy Farm Project No. 1: residue burning impacts on residue C and nutrient losses. (Huggins-C,N,P,S losses, site-specific RUSLE and SCI estimates; Painter-economic analyses with aid from Wetterau and Davis).

Objective 1 Methods: This study was conducted at the Cook Agronomy Farm (CAF) within the 140 acres that have been managed using continuous direct-seeding since 1999. At the CAF, 369 geo-referenced points have been established and monitored for a number of soil, crop and economic variables. Background data pertinent to this objective are characterization of soil C, N, S and pH at the geo-referenced points (0 to 5 feet) as well as wheat performance (e.g. yield, quality, net return). Loss of C and N from residue burning were assessed by difference. Treatments (12 ft by 12 ft areas) consisted of: (1) fall burning of winter wheat residues; (2) spring burning of winter wheat residues; and (3) no burning of winter wheat residues. The three treatments were randomly assigned and burn treatments applied following previously used methods (see Huggins et al., 2005, DOE Final Report). The three treatments were located at 15 different field locations that capture the range in winter wheat residue loads (low to high) (Figure 1). Prior to burning, all wheat residue was removed on 2 subplots (0.5 m^2) randomly located within each applicable treatment. Following the burn treatment, all remaining wheat residue and burned remnants were removed from 2 additional randomly located subplots (0.5 m^2). All residue samples were analyzed for total C and N using standard laboratory methods (Leco C/N analyzer). Statistical analyses (AOV) assessed treatment effects on wheat residue loads and associated C and N. Soil samples (0-20 cm) from each of the three treatments and 15 sites were collected and analyzed for soil pH (1:1 with water) total C, N (Leco analyzer), particulate organic C, N (a measure of labile components), potentially mineralizable N and bulk density. Yields of the subsequent spring wheat crop were assessed for each treatment at the 15 field locations.

To aid assessment of burn treatment effects on soil nutrient availability, anion and cation PRS (Plant Root Simulator)™-probes from Western Ag. Innovations (WAI) were used in both field and laboratory studies (Figure 2). In the field, PRS-probe pairs (anion and cation, 4 pairs per plot) were deployed in the spring at the time of planting spring wheat in the fall burn and control (no burn) treatments in plots without any applied fertilizer. Five locations (replications) out of the 15 total were used for this study. The PRS-probes were deployed in the surface 20-cm, collected after 24 hours and then new probes were placed in the same locations for one week intervals for five weeks. In the laboratory, soil samples (0-20 cm) from five replications of the fall burn and control treatments were packed into 1-pint mason jars to achieve a bulk density of 1 g cm^{-3} and watered to maintain field capacity (3 laboratory replications were used). Probe pairs were deployed for 24 hours and then at 7 day intervals for four weeks. The probes were then analyzed for NO3-N, NH4-N, Ca, Mg, K, P, Fe, Mn, Cu, Zn, B, S, Pb and Al using ICP. Data are expressed as µg nutrient 10 cm^{-2} per unit time.

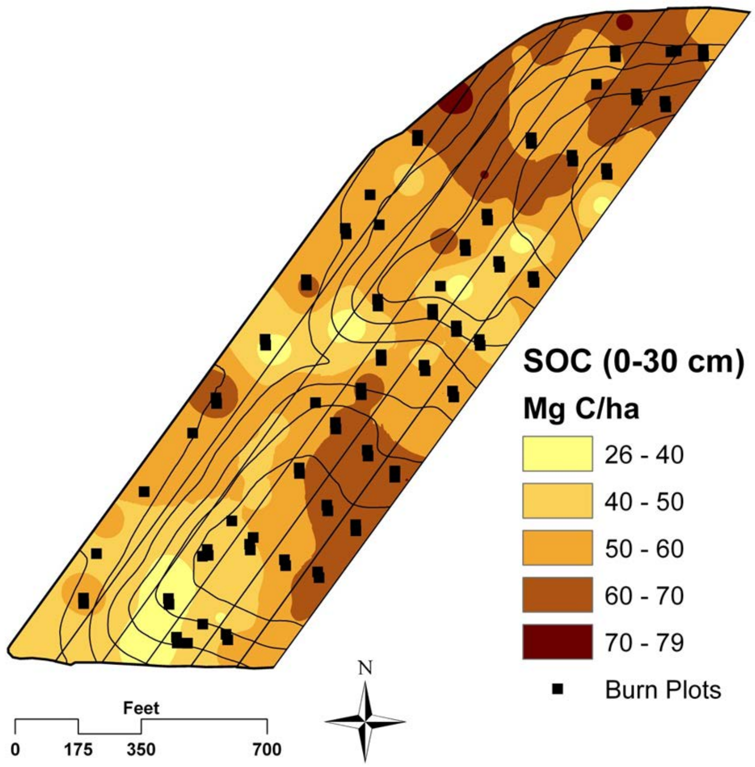

Figure 1. Location of field plots for Cook Agronomy Farm Projects No. 1 and 2. Also displayed are the soil organic C (SOC) levels from 1999 sampling for the surface 30 cm. Sample locations were selected to represent the full range of SOC conditions across the 30 ac field.

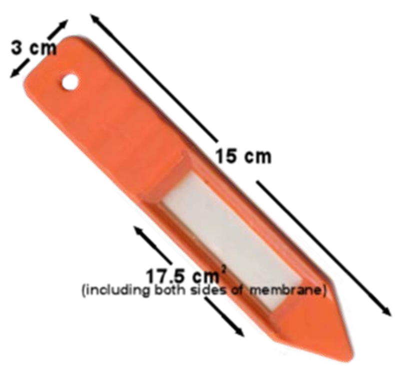

Figure 2. PRS (Plant Root Simulator) anion probe on left; Anion and cation PRS-probes inserted into soil for laboratory incubations over 24-hr and then 7 day intervals for 4 weeks.

Objective 1 Results and Discussion: Fall burning reduced surface winter wheat residue by 62% whereas spring burning reduced residues by 55% (Table 1), similar to amounts reported by others (Air Sciences Inc., 2003). Winter wheat residue had decreased by 36% from the time of the fall burn to the spring burn due to residue decomposition and/or mixing with soil by biota. Residue C percentage remained unchanged by the fall burning treatment but increased slightly with the spring burn. Overall, 2,010 lbs C/ac were lost from fall burning while 1,271 lbs C/ac were lost during the spring burn. The percent N in the residue increased following fall and spring burning as well as between the fall and spring burns (Table 1). The average amount of N lost by burning, however, was similar with 12 lbs N/ac lost during the fall burn and 11 lbs N/ac lost during the spring burn. This occurred as a greater percentage of winter wheat residue N was lost during the spring burn (40%) than during the fall burn (33%). These N losses are appreciably lower than the previously reported losses of nearly 100% reported from laboratory studies of residue burning (Heard et al., 2006). Losses of K, P and S from fall burning averaged 27.4, 1.0 and 2.6 lbs/ac, respectively. Losses of K, P and S from spring burning were less than what occurred in the fall averaging 3.8, 0.7 and 1.1 lbs/ac, respectively (Table 1). The K losses were unexpected as K would not be oxidized during residue burning and are currently unexplained.

Table 1. Fall and spring burning effects on winter wheat residue loads and residue C and N percentages and contents. Values with following letters that are different across a row are statistically different (p = 0.05).

Winter Wheat Residue	**Fall Burn**		**Spring Burn**	
	Pre-burn	**Post-burn**	**Pre-burn**	**Post-burn**
Residue (lbs/ac)	8093a	3059c	5168b	2354c
Residue N (%)	0.44d	0.78a	0.52c	0.69b
Residue C (%)	39.9b	39.9b	43.0a	40.5b
Residue K (%)	0.456a	0.389a	0.130b	0.130b
Residue P (%)	0.034c	0.061a	0.035c	0.047b
Residue S (%)	0.056b	0.065a	0.046c	0.055b
Residue C/N	92.0a	54.5b	84.6a	59.5b
Residue N (lbs/ac)	35.9a	24.2c	27.3b	16.3d
Residue C (lbs/ac)	3228a	1218c	2226b	955c
Residue K (lbs/ac)	38.82a	11.47b	6.90b	3.07c
Residue P (lbs/ac)	2.82a	1.79c	1.85b	1.13d
Residue S (lbs/ac)	4.56a	1.95b	2.39b	1.32c

Losses of major nutrients from fall and spring burning were assessed economically using the cost of fertilizer required to replace N, K, P and S (Table 2). Fertilizer replacement costs for fall burning were nearly three times greater than for spring burning. A large part of the costs were for replacing K losses which were unexpected. The study will be repeated during the 2011-2012 year to verify this and other losses.

Table 2. Fertilizer replacement cost for nutrient loss during fall and spring burning of winter wheat residue.

Residue Nutrients	**Fertilizer Cost† ($/lb)**	**Fall Burn Nutrient Loss ($/ac)**	**Spring Burn Nutrient Loss ($/ac)**
N	0.45 (82-0-0)	5.27	4.95
K_2O	0.62 (0-0-60)	20.40	2.83
P_2O_5	0.73 (10-34-0)	1.72	1.20
S	0.47 (12-0-0-26)	1.23	0.66
Nutrient Replacement Cost		28.62	9.64

†Average fertilizer prices ($/lb of nutrient) for 2008, 2009 and 2010 from Idaho Input Cost publication series (http://www.cals.uidaho.edu/aers/r_crops.htm). Price of nitrogen in these formulae are based on the price for anhydrous ammonia nitrogen.

Residue burning had little impact on soil properties measured (Table 3). Soil N%, soil C%, soil C/N ratio, bulk density, soil pH and particulate organic matter (POM) C/N ratio remained unchanged. The fall burn did, however, increase both the particulate organic N (PON) as well as the particulate organic C (POC) as compared to pre-burn and spring burn measurements. These results may, in part, be due to the increase in residue N% that occurred following the fall burn (Table 1).

Table 3. Fall and spring burning effects on soil properties measured. PON=particulate organic N; POC=particulate organic C; POM=particulate organic matter. Values with following letters that are different across a row are statistically different (p = 0.05).

Soil Property	Control	Fall Burn	Spring Burn
Soil N (%)	0.15a	0.16a	0.16a
Soil C (%)	1.84a	1.88a	1.80a
Soil C/N Ratio	11.84a	11.92a	11.48a
Bulk Density (g/cm^3)	1.33a	1.34a	1.34a
Soil pH	6.04a	6.18a	6.03a
PON (%)	2.27b	2.58a	2.27b
POC (%)	32.2b	36.9a	32.0b
POM C/N Ratio	14.3a	14.3a	14.2a

Residue burning did not affect spring wheat yields in fertilized treatments (Table 4). In plots without N fertilizer, however, fall burning did increase yield indicating that applied N compensated for the effects of fall burning. Interestingly, the harvest index and N harvest index were both greater in non-fertilized (N) as compared to applied N treatments.

Table 4. Residue burning and applied fertilizer effects on spring wheat yield and N characteristics. Values with following letters that are different across a row are statistically different (p = 0.05).

	Control		Fall Burn		Spring Burn	
Spring Wheat	N Applied	No N Applied	N Applied	No N Applied	N Applied	No N Applied
Grain Yield (bu/ac)	59a	47b	57a	53a	53a	45b
Grain Protein (%)	11.0a	9.1b	11.4a	8.9b	11.4a	8.8b
Crop Residue (lbs/ac)	5116a	2784c	5055a	3540b	4922a	3177b
Harvest Index (%)	0.37b	0.47a	0.38b	0.44a	0.36b	0.43a
Grain N (%)	1.92a	1.60b	2.00a	1.55b	2.00a	1.54b
Grain N (lbs/ac)	52.0a	34.8b	52.1a	38.3b	48.8a	32.6b
Crop Residue N (%)	0.45a	0.30b	0.51a	0.30b	0.49a	0.28b
Crop Residue N (lbs/ac)	22.9a	8.3b	25.3a	10.6b	23.7a	9.1b
N Harvest Index (%)	0.70b	0.81a	0.68b	0.79a	0.67b	0.78a
Crop Residue C (%)	44.6a	44.5a	44.5a	44.6a	44.4a	44.5a
Crop Residue C (lbs/ac)	2282a	1240c	2246a	1578b	2188a	1413b

Fall burning of winter wheat residue did affect early season soil N availability, spring wheat growth and development and spring wheat N uptake as compared to controls with no burning (Table 5, Figure 2). Spring wheat in fall burned treatments had significantly more main stem leaves than controls indicating that soil temperatures were more favorable following burning. This would be expected as the surface following burning would adsorb more energy from the sun. Aboveground N uptake at this early stage (tillering) was 112% greater in fall burned as compared to control plots. No treatment differences were found in pre-plant soil test N (0-20 cm) using traditional KCl extracts, however, the field deployed PRS probes had 40% more µg N 10 cm^{-2} 7 $days^{-1}$ in fall burned as compared to control plots. The relationship between plant N uptake and the PRS probe data was linear and highly significant (Figure 2), while no significant relationship was found between plant N uptake and KCL-extracted N (Figure 3). Differences in other nutrient availability (P and S shown) were minimal between the burned and unburned plots. These data show that both lower temperatures and N availability are limiting spring wheat growth following winter wheat crops that produce large amounts of surface residue. The fall burning in this study resulted in more favorable soil temperatures and an increase in available N. The greater soil availability of N is likely a consequence of less N immobilization (tie-up) from microbial decomposition of wheat residues.

Table 5. Fall burning of winter wheat residue effects on subsequent spring wheat growth and development, early N uptake and nutrient availability (no applied N plots). Values with following letters that are different across a row are statistically different (p = 0.05).

Spring Wheat and Soil Properties	Control	Fall Burn
Main Stem Leaves (no)	3.94b	4.53a
Tillers (no)	1.26a	1.61a
Plant N (%)	3.3b	3.9a
Plant Dry Weight (lbs/ac)	96b	176a
Plant N (lbs/ac)	3.3a	7.0b
Extracted Soil NO_3-N, Day 1, (ppm)	21.5a	24.1a
PRS probe Nitrate-N, Day 1, Field, (µg 10 cm^{-2} $24hr^{-1}$)	10.7a	21.8a
PRS probe Nitrate-N, Day 1, Lab, (µg 10 cm^{-2} $24hr^{-1}$)	31.7a	28.3a
Extracted Soil NO_3-N, 28-day Incubation, (ppm)	34.1a	36.1a
PRS probe Nitrate-N, 7 Days, Field, (µg 10 cm^{-2} $7days^{-1}$)	62.5b	87.8a
PRS probe Nitrate-N, 7 Days, Lab, (µg 10 cm^{-2} $7days^{-1}$)	123.9a	139.6a
PRS Probe P, Day 1, Field, (µg 10 cm^{-2} $24hr^{-1}$)	0.80a	0.56a
PRS Probe P, Day 1, Lab, (µg 10 cm^{-2} $24hr^{-1}$)	0.60a	0.52a
PRS Probe P, 7 Days, Field, (µg 10 cm^{-2} $7days^{-1}$)	1.64a	1.45a
PRS Probe P, 7 Days, Lab, (µg 10 cm^{-2} $7days^{-1}$)	0.64b	0.90a
PRS Probe S, Day 1, Field, (µg 10 cm^{-2} $24hr^{-1}$)	19.6a	19.6a
PRS Probe S, Day 1, Lab, (µg 10 cm^{-2} $24hr^{-1}$)	17.9a	17.2a
PRS Probe S, 7 Days, Field, (µg 10 cm^{-2} $7days^{-1}$)	26.4a	24.7a
PRS Probe S, 7 Days, Lab, (µg 10 cm^{-2} $7days^{-1}$)	20.3a	21.7a

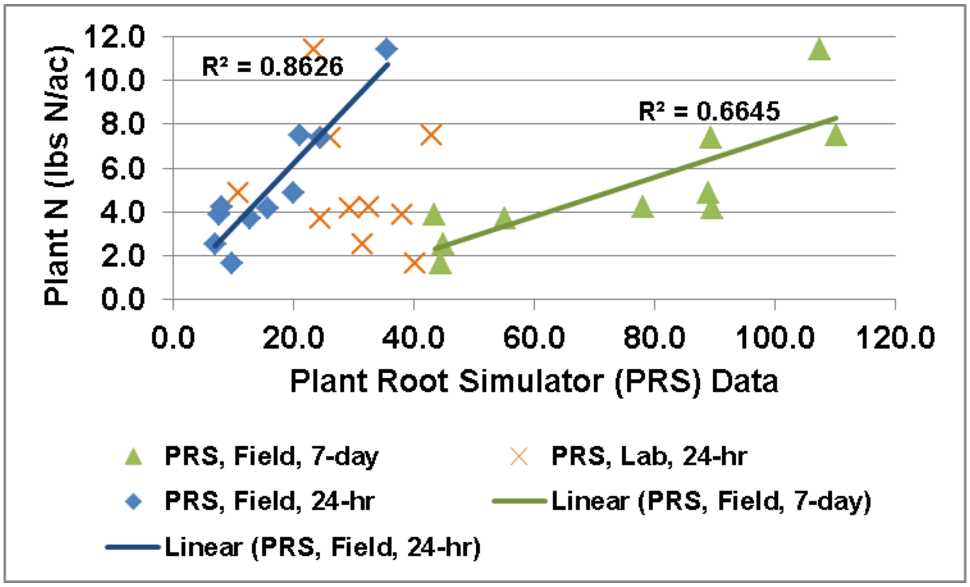

Figure 2. Relationship between spring wheat N uptake (tillering stage) and PRS-probe data (µg N $10cm^{-2}$ $time^{-1}$) combining control and fall burn data.

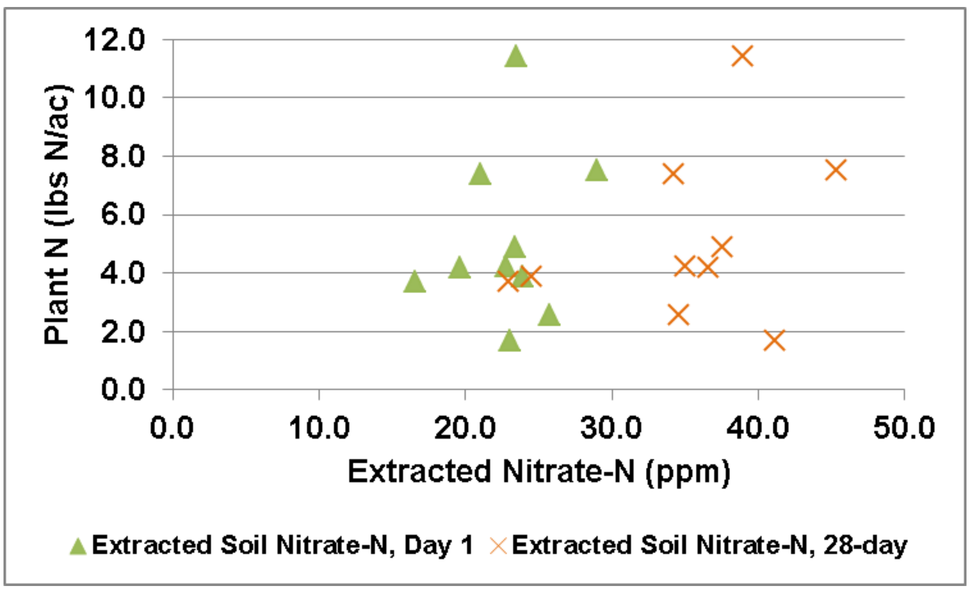

Figure 3. Relationship between spring wheat N uptake (tillering stage) and KCl extracted Nitrate-N (ppm) combining control and fall burn data.

Objective 2: Identify and economically assess crop rotations and sequences that benefit from retaining winter wheat residues in direct-seed systems. Cook Agronomy Farm Project No. 2: crop sequence and rotation alternatives that make burning unnecessary. (Huggins-crop yield and quality; Painter-economic analyses with aid from Wetterau and Davis)

Objective 2 Methods: This objective consisted of two studies: (1) evaluation of spring chickpea performance (yield, net returns) following winter wheat under tillage, burning and direct-seed treatments (**sequence study**); and (2) evaluation of direct-seed crop rotation alternatives following winter wheat with and without burning (**rotation study**). The crop **sequence study** was located on the CAF where a randomized-block, small-plot (15 ft by 40 ft) experiment with four replications where chickpeas were established using five different treatments following winter wheat. Treatments were: (1) conventional tillage; (2) fall burning and direct seeding with a low disturbance drill (Cross-slot drill); (3) spring burning and direct seeding with a low disturbance drill (Cross-slot drill); (4) no burning and direct seeding with a low disturbance drill (Cross-slot drill);and (5) no burning and direct seeding with a high disturbance drill (Horsch-Anderson drill). Crop yield and net returns will be assessed using partial enterprise budgets. The **rotation study** was located within the 92 acres of the main crop rotation experiment of the CAF. Here, treatments were established following winter wheat harvest to assess impacts on subsequent crops which will be: winter wheat, spring chickpea and spring barley. These treatments were part of the following three-year crop rotations: (1) winter wheat/spring chickpea/spring wheat; (2) winter wheat/winter wheat/spring chickpea; and (3) winter wheat/spring barley/spring wheat. Treatments consisted of fall burn and no burn on small plots (12 ft by 12 ft) established in high and low wheat residue field locations with ten replications (30 total plots). All field crops were seeded with a Horsch-Anderson direct-seed drill (hoe-type opener). Crop performance (yield) was evaluated for all treatments.

Objective 2 Results and Discussion: Rotation study: Plot establishment for the rotation study (2010) largely failed due to poor drill performance and weed control issues during the unusually wet spring. Yield data were collected and analyzed, however, no meaningful results were obtained. This study is being repeated in 2011.

Sequence study: Winter wheat and spring chickpea yields were not significantly different between fall burn and control treatments (Table 5). Winter wheat averaged 82 bu/ac while spring garbonzo beans averaged 1629 lbs/ac, both crops were planted in five acre fields with terrain and soil variability typical of this region of the Palouse (Figure 1). In contrast, spring barley yields were 11% greater following fall burning as compared to controls (no burning). The excellent yields of spring garbonzo beans following winter wheat identify this crop as a good rotation alternative under direct seeding.

Table 5. Fall burning of winter wheat residue effects on subsequent winter wheat, spring garbonzo bean and spring barley yields. Values with following letters that are different across a row are statistically different (*p* = 0.05).

Crop	Control	Fall Burn
Winter Wheat Yield following Winter Wheat, (bu/ac)	82a	82a
Garbanzo Bean Yield following Winter Wheat, (lbs/ac)	1624a	1634a
Spring Barley Yield following Winter Wheat, (lbs/ac)	4733b	5234a

Objective 3: Document effects of wheat straw management and rotation alternatives on root pathogens.
Cook Agronomy Farm Project No. 3: crop rotations as alternatives to burning for root disease management on dryland wheat. (Paulitz-plant pathology with aid from Wetterau and Davis).

Objective 3 Methods: This objective relied on the small plot studies established for the spring wheat study in Objective 1 with control, fall burning, and spring burning treatments. Fusarium crown rot was quantified on 15 plants at the end of the season by evaluating the number of internodes with discoloration on the main tillers of each plant. Another rating was done based on the severity of the discoloration.

Objective 3 Results: When non-fertilized and fertilized plots were analyzed together, there was no effect of residue treatments, but fertilizer had a significant effect. More disease was found in the fertilized plots than the non-fertilized plots in the control treatments, but this effect was not seen in the burn treatments (Fig. 4, 5).

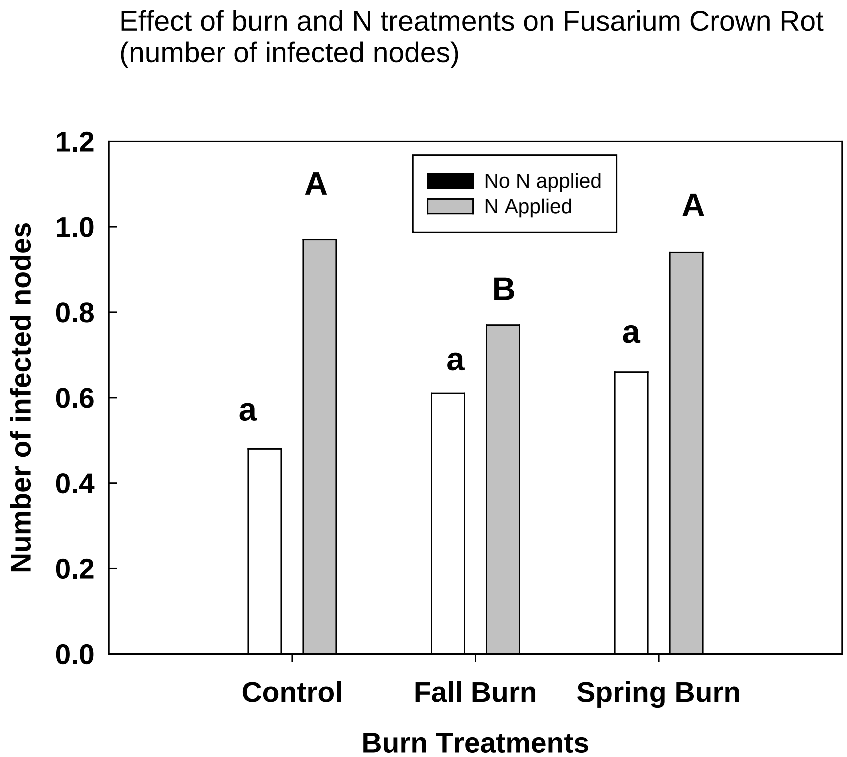

Figure 4. Effect of burn and N treatments on Fusarium Crown Rot (number of infected nodes)

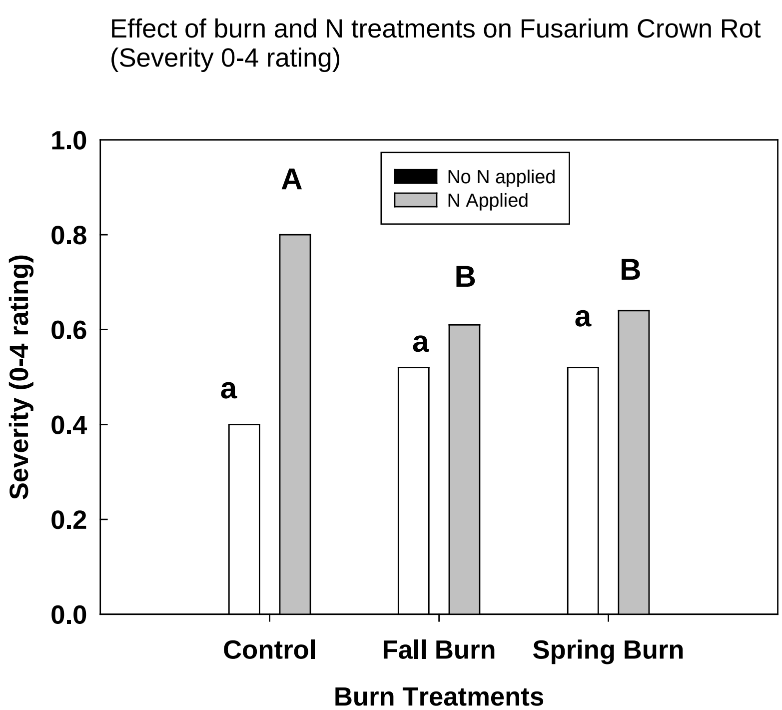

Figure 5. Effect of burn and N treatments on Fusarium Crown Rot (Severity 0-4 rating).

When analyzed with just the fertilized treatments, burning had a significant effect where less disease was found in the burn treatments (Figures 6 and 7).

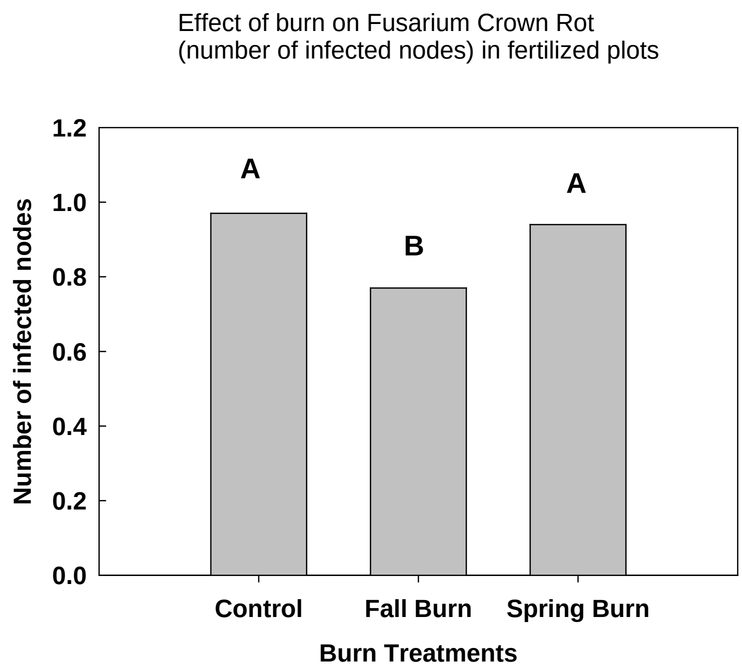

Figure 6. Effect of burning on Fusarium Crown Rot in fertilized plots.

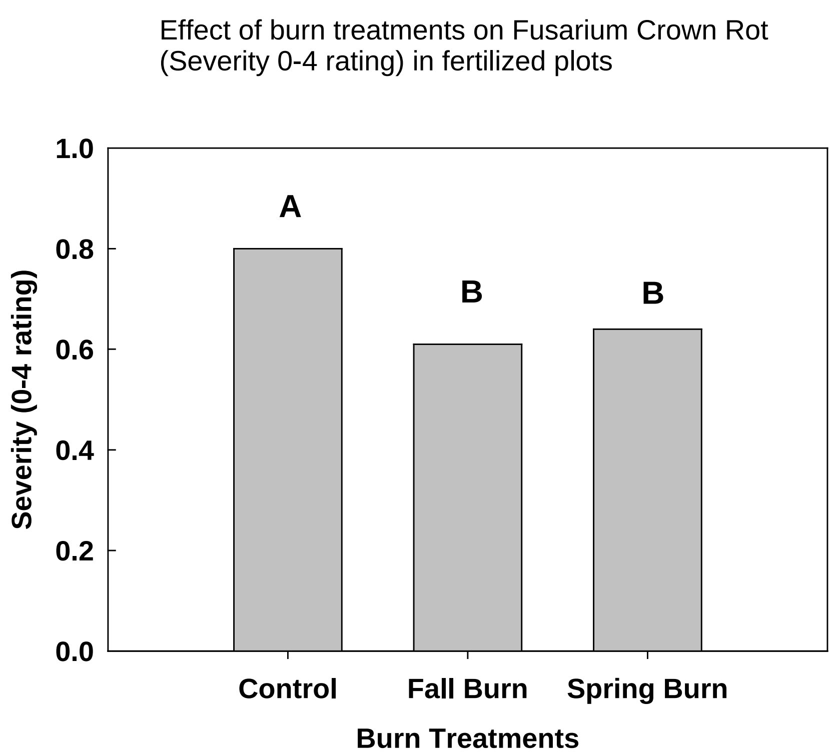

Figure 7. Effect of burn treatments on Fusarium Crown Rot in fertilized plots.

Despite the low level of disease in 2010, the DOE study demonstrated less disease in the treatments with burning, and higher disease with N fertilizer. From previous studies, we have both *F. pseudograminearum* and *F. culmorum* on the Cook Farm, and both survive in the above ground residue.

Objective 4. Convey project findings through electronic and print media, field days, conferences and research site tours (Huggins, Paulitz and Painter). As research results become available, many opportunities for presentations at field days, conferences and research site tours will occur. Each of the co-principle investigators gives over 15 grower-oriented presentations each year regarding their research. In addition, yearly reports and publication of results in popular and scientific journals are expected.

Results from the project will be presented at this years (2011) WSU Cook Agronomy Farm Field Day.

References

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