# Crop Rotation and Stubble Management: Alternatives to Burning


**Final Report**

Submitted to DOE Agricultural Burning Practices and Research Task Force, 2005

**Title:** Straw Management and Crop Rotation Alternatives to Stubble Burning: Final Report

**Submitted to:** Agricultural Burning Practices and Research Task Force

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## Executive Summary

Burning crop residues such as wheat stubble can have negative impacts on air quality, the productivity of soil resources, and water quality (e.g. from soil erosion). Nevertheless, farmers in eastern Washington have few alternatives besides burning and/or inversion plowing to manage the large quantities of wheat straw after harvest. This project examined stubble management alternatives to burning including crop rotation and harvest and post-harvest stubble management in direct-seed systems. Direct-seeding is a farming method where crops are seeded directly into the residues of the previous crop with little soil disturbance. Using direct-seeding eliminates soil erosion, sequesters carbon in the soil, and significantly reduces fuel consumption and labor needs. However, problems associated with disease and weed control, the need for specialized equipment, and learning new ways to manage crops, pose significant barriers to adoption by farmers.

**Significant findings of the project are:**

1. Crop rotation is a powerful residue management tool in direct-seed systems. Rotation strategies where fall-sown crops are established into relatively large residue loads while spring-sown crops are established following crops with low post-harvest residues looked promising and needs to be further evaluated. Also, small-seeded spring crops such as spring canola (an oil-seed crop) performed well following winter wheat. However, further analyses, particularly economic, and more growing seasons are required to reach conclusions with sufficient scientific basis to support changes in grower practices and government policy. Proceed with caution.
2. None of the residue management treatments which included stubble sizing and harrowing showed any advantages or disadvantages for direct-seeding wheat; however, overall crop performance (yield) was likely compromised by direct-seeding wheat into relatively large surface residue loads.
3. Direct-seeded winter barley yielded well as an alternative crop, however, both growth and grain yield responded positively to fumigation and burning treatments. These data indicated that further residue management through either row cleaners, greater disturbance during planting (e.g. hoe-type openers) or a paired-row configuration could benefit winter barley performance.
4. Burning was not effective in reducing the pathogens studied (Fusarium, Rhizoctonia and Take-all) by directly killing them. Burning, however, often improved the early growth of seedlings, likely by creating warmer soil conditions (less surface residue). Soil-borne pathogens were still yield-limiting in our experiments, based on the yield increase seen with soil fumigation. No consistent differences occurred among the straw management alternatives that could be attributable to an effect on root diseases or pathogens. Most likely, these methods have an indirect effect on the pathogen by altering the environment of the soil, and making conditions more or less favorable for disease development.
5. Finally, finding viable alternatives to burning residues is still an active area of research. It is likely that many different strategies including those studied in this project will contribute toward the development of viable alternatives to burning. It is unlikely that any one practice will replace burning in the design of future agricultural systems that are more economically viable and environmentally sound.

## Introduction

Burning crop residues such as wheat stubble can have negative impacts on air quality, the productivity of soil resources, and water quality (e.g. from soil erosion). Nevertheless, growers are faced with few alternatives besides burning and/or inversion plowing in order to manage the large quantities of wheat straw following harvest. These practices have long been used to aid the management of diseases and weeds and to enable the planting of the next crop. Environmentally and economically viable alternatives to burning or plowing wheat stubble are needed in both dryland and irrigated wheat-based cropping systems of Washington and Idaho. This project examines crop rotation, stubble management and planting geometry in direct-seed systems to evaluate their viability as alternatives to residue burning. Direct-seeding is a farming method where crops are seeded directly into the residues of the previous crop with little soil disturbance. Using direct-seeding eliminates soil erosion, sequesters carbon in the soil, and significantly reduces fuel consumption and labor needs; however, problems associated with disease and weed control, the need for specialized equipment, and learning new ways to manage crops, pose significant barriers to adoption by farmers. In addition, farmers using direct-seed techniques have often resorted to burning wheat residue to help overcome these barriers. Our overall goal is to advance the science of direct-seed farming systems by addressing major adoption barriers in ways that decrease the reasons growers currently have for burning stubble.

## Background

A logical strategy for managing wheat straw without burning in direct-seed systems, and the strategy used in this study, is to depend first on crop rotation; second on mechanical treatment such as stubble trimming, harrowing, flailing, or a combine stripper header; and third on drill characteristics such as row-spacing and configuration, opener type, and row cleaners. This project focused on wheat straw management without burning in both dryland and irrigated wheat-based cropping systems. Under dryland conditions at the Washington State University (WSU) Cunningham Agronomy Farm near Pullman, WA, a 2-year rotation of spring wheat/winter wheat and a 3-year rotation of spring wheat/winter wheat/alternative crop were evaluated with different residue management treatments. Under irrigation at the WSU Lind Research Station, Lind WA, a 3-year rotation without burning was compared with continuous winter wheat that includes both burning and plowing. For mechanical treatment of wheat stubble, we focused on shorter rather than longer stubble and on chopping/spreading the straw to facilitate faster breakdown on the soil surface. Finally, we continued to test paired-row spacing, a concept shown in earlier work (Cook et al., 2000) to help offset surface residue effects that promote soil-borne root diseases.

In the 2- and 3-year crop rotations our goal with back-to-back spring and winter wheat is to average 150 bu/A for the combined two years of wheat. Where an alternative crop is planted between the winter and spring wheat crops (3-year rotation), we expect the alternative crop to at least break even economically and provide some rotation benefits to the subsequent wheat crop. The 2-year spring/winter wheat rotation is also a flex rotation where spring wheat can be grown twice before returning to winter wheat if grass weeds become a problem. A unique feature of the 3-year crop rotations is that winter wheat is planted following spring wheat rather than the converse as is done routinely in the high-production regions of eastern Washington, while spring wheat is direct-seeded into an alternative crop (peas, lentils, canola, or barley). Advantages for this sequence in the design of a direct-seed cropping system are as follows.

1. Crop rotation is used as a major crop residue management tool, thereby greatly reducing or eliminating the need for burning. For example, there is considerably less straw to manage when planting winter wheat into spring wheat stubble as compared to doing the reverse. Direct-seeding spring wheat into relatively low residue amounts left by peas, lentils or canola greatly reduces spring planting barriers created by large quantities of winter wheat stubble.

2. The 3-year rotation options emphasize planting of fall crops in two of three years, where fall crops are planted into relatively high residues after cereals and spring wheat is planted into relatively low amounts of residue after legumes or canola. Furthermore, the emphasis on fall crops increases overall crop yield potential and shifts the majority of planting operations from the spring to the fall where the time period with conditions suitable for planting and associated farming operations are larger, thus reducing the rational for burning.

3. Crop rotation is used to manage the “green bridge” further limiting soil-borne disease potential and the rational for burning crop residues. Green bridge effects are most problematic when direct-seeding spring cereals into winter wheat stubble due to over-wintering volunteer wheat and weeds. The potential for situations arising where the green bridge can impact yield is greatly reduced when spring planting cereals after broadleaf crops such as canola, peas and lentils or in planting of fall crops (peas, lentils and winter wheat) after spring wheat.

4. Foot rot of winter wheat, caused by *Pseudocercosporella herpotrichoides*, is a non-issue in this rotation because of the late seeding of the winter wheat, and therefore the variety of winter wheat can be selected based on quick-breakdown properties of the straw, e.g., Cashup, Bundage 96, or Falcon. This limits the need to use a foot rot resistant variety such as Madsen that has tough straw, is slow to decompose and increases the rational for burning.

5. There is likely less root disease pressure presented by the roots and crowns of spring wheat (because of its short life cycle) compared to roots and crowns of winter wheat that have 10 months or longer between planting and maturity to become infected/infested.

6. The soil warms and dries faster in the spring after peas or other broadleaf crops than when covered with winter wheat stubble, providing better conditions for direct-seeding and emergence of spring wheat and a larger spring “window” for planting operations, thus replacing the need to burn large quantities of residue to facilitate spring farming operations.

7. Spring barley can be substituted for the peas, canola, or other broadleaf crop in the 3-yr rotation, providing a continuous-cereal system, with spring barley planted into winter wheat

stubble, followed by spring wheat into the barley stubble, so as to avoid the problem of "volunteer" barley in a following winter wheat crop.

Disadvantages of these cropping systems are as follows.

1. The yield of winter wheat following spring wheat will likely be less than that after spring peas or other broadleaf crop, although data on how much yield reduction can be expected are lacking. We likely will capture, however, favorable rotation effects of the broadleaf crop on yields of spring wheat compared to yields when direct seeding into winter wheat stubble. Our goal, which to date we have achieved, is to produce 150 bu/A for back-to-back spring and winter wheat yields combined, i.e., every two years. We will likely exceed this goal as we gain more experience.

2. Volunteer spring wheat has occurred routinely in direct-seed winter wheat over the past 4-5 years due to mild winters, thereby presenting the potential for mixed wheat classes. We use the same market class of winter wheat after spring wheat, e.g., soft white winter wheat after soft white spring wheat for the 2-yr rotation, and hard red winter wheat after Dark Northern Spring wheat for the 3-yr rotations.

3. The challenge of direct-seeding into heavy winter wheat stubble still exists for the alternative crops in the 3-yr rotation and for the spring wheat in the 2-yr spring/winter wheat rotation. These large residue quantities, however, may actually benefit the establishment and over-wintering of winter peas, lentils and barley as residues conserve seed-zone water and provide greater winter protection (Huggins and Pan, 1991). The residue management treatments in this study were designed to help overcome the residue barrier created by winter wheat stubble to direct-seed systems without the aid of burning. We also addressed this problem by moving toward varieties of winter wheat having straw that "breaks down" more readily.

## Research Objectives

This project examined crop rotation, stubble management and planting geometry with direct-seeding as alternatives to residue burning under both dryland and irrigated wheat-based cropping systems.

Specific project objectives were to:

1. Determine the agronomic benefits, if any, of different rotation strategies for direct-seed systems;
2. Determine agronomic benefits, if any, of shortening wheat stubble with or without further spreading, to growth and yield of direct-seeded wheat;
3. Determine effects of residue management and paired-row spacing as an approach to offset the disease-favoring effects of winter wheat stubble on a fall-sown cereal (winter barley);
4. Document effects of cereal straw management and rotation alternatives on root pathogens; and
5. Convey project findings through electronic and print media, conferences and research site tours.

## Methods and Outcomes by Objective

**Objective 1. Determine the agronomic benefits, if any, of different rotation strategies for direct-seed systems.**

<u>Methods</u>

Different crop rotations under continuous direct-seeding were established on a 92 acre portion of the Cunningham Agronomy Farm in large sections and strips (Figures 1 and 2) in 2001 following two seasons of direct-seed crops: hard red spring wheat in 1999 and spring barley in 2000. The three-year rotations consist of hard red winter wheat-alternative crop-hard red spring wheat. Alternative crops consist of winter and spring counterparts of canola, peas and barley and comprise six different crop rotations. The alternative crops are established each year in strips that go across different soil types and topography and follow winter wheat on approximately 1/3 of the farm. Each alternative crop strip is about five acres. Spring wheat is planted across all of the alternative crops the next year. Therefore, each year this portion of the farm is approximately 1/3 winter wheat, 1/3 spring wheat and 1/3 alternative crop. All crops are direct-seeded with a Great Plains no-till drill equipped with a leading turbo-coulter with low-pressure liquid fertilizer injection followed by double disks for seed placement. Crop performance (yield, protein) is sampled at 369 geo-referenced points (Figure 1) that on average represent a point every 30 m. The samples are collected by hand on a 2-m by 1-m geo-referenced plot located using a global positioning system (GPS). Grain protein for wheat is determined using dry combustion to analyze total N concentration in the grain which is then multiplied by 5.7 to calculate grain protein percentage. Since the rotations were established in 2001, yield and protein data that are representative of the three-year rotation do not occur until 2003.

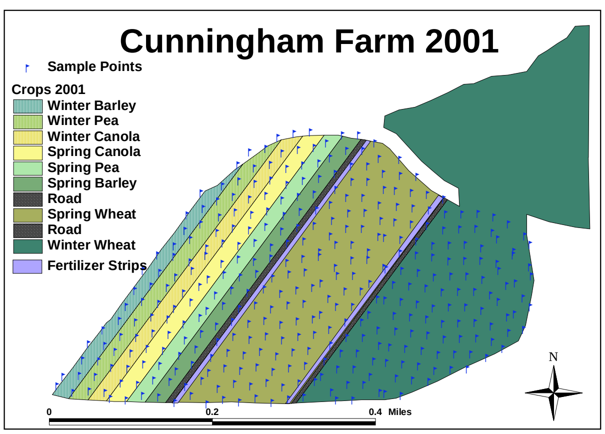



Figure 1. Field layout of Cunningham Agronomy Farm crops in 2001 and 369 geo-referenced sample locations.

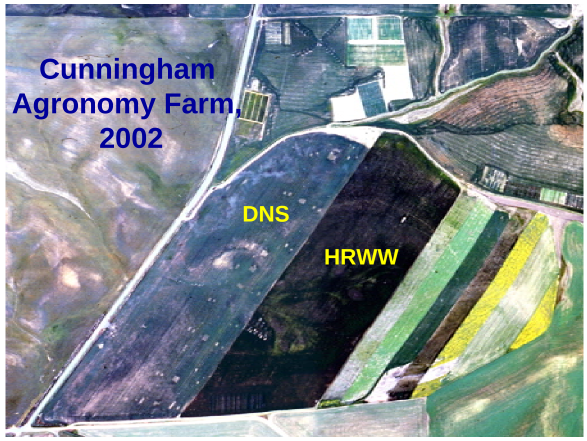



Figure 2. Aerial photo of Cunningham Agronomy Farm showing field locations of hard red spring wheat (DNS) hard red winter wheat (HRWW) and alternative crops (eight strips on right side of photograph). The alternative crops from left to right consist of winter canola, winter pea, spring barley, winter barley, spring canola, spring pea, spring pea, spring canola. Two strips of spring peas and canola were established to compensate for short strip lengths.

Outcomes

Yield and protein data are summarized for the 2002, 2003 and 2004 crop years (Figures 3 and 4). It should be recognized that data assessing crop rotation effects on yield and protein are preliminary as these studies require several cycles of a rotation to properly evaluate. Nevertheless, these data provide insights into possible rotation effects in direct-seed cropping systems.

**HRSW, 2004**

| Pre. Crop | Yield |
|---|---|
| Canola | 83 bu/A |
| Barley | 87 bu/A |
| Peas | 88 bu/A |

Protein: 12.7%

**HRSW, 2003**

| Pre. Crop | Yield |
|---|---|
| Canola | 55 bu/A |
| Barley | 51 bu/A |
| Peas | 56 bu/A |

Protein: 13.7%

**HRSW, 2002**

| Previous crop | Yield | Protein |
|---|---|---|
| Canola | 68 bu/A | 13.5% |
| Barley | 73 bu/A | 13.0% |
| Peas | 75 bu/A | 14.0% |

Figure 3. Yield and protein percentage for hard red spring wheat (HRSW) following different previous crops (Pre. Crop) in 2002-2004. Upper picture shows visual comparison of pea versus barley stubble following direct-seeding of HRSW. Lower picture shows spring wheat crop at the Cunningham Agronomy Farm.

In 2002, HRSW yield was greater following peas as compared to canola. Grain protein of HRSW following peas was also greater than when following barley. Consequently, rotation advantages for HRSW following peas likely include increases in both yield and protein.

Direct-seeding HRSW into pea stubble was easily achieved and would be feasible for a variety of direct-seed planting equipment.  Other observations comparing seedbed conditions following the alternative crops include: (1) pea ground dried out earlier in the spring and more quickly following spring precipitation than barley ground; (2) HRSW grain yield was comparatively lower in 2003 than in either 2002 or 2004 due to drier conditions.

These results for HRSW emphasize the importance of crop rotation for minimizing the reasons to burn crop residues in direct-seed systems.  Direct-seeding of spring wheat into large quantities of residue produced by a previous wheat or barley crop are avoided. Economic trade-offs, however, have not been assessed at this point in time and are a goal for future studies.  One major question is whether or not the increase in spring wheat performance following peas offsets any yield disadvantage for winter wheat that is planted after the spring wheat crop, as compared to a traditional three-year, tillage-based rotation where spring wheat follows winter wheat and winter wheat follows peas.

Average yield of direct-seeded hard red winter wheat crops following hard red spring wheat ranged from 80 bu/A in 2002 to 94 bu/A in 2004.  One goal to preliminarily assess the performance of both spring and winter wheat in the direct-seed rotations was to produce a combined yield of 150 bu/A of wheat over the course of three years.  This goal has been achieved for the 2002 through 2004 period as yields of both winter and spring wheat have combined to average 156 bu/A.  Only in 2003 was this goal not achieved, when dry conditions adversely impacted spring crops more so than winter crops.  Grain protein levels for HRWW ranged on average from 10.6 to 11% (Figure 4).  These levels were below the target of 11.5%.  Developing decision aids for managing nitrogen fertilizer inputs with variable rate and timing of application to improve crop performance and nitrogen use efficiency is an on-going research focus at the Cunningham Agronomy Farm.

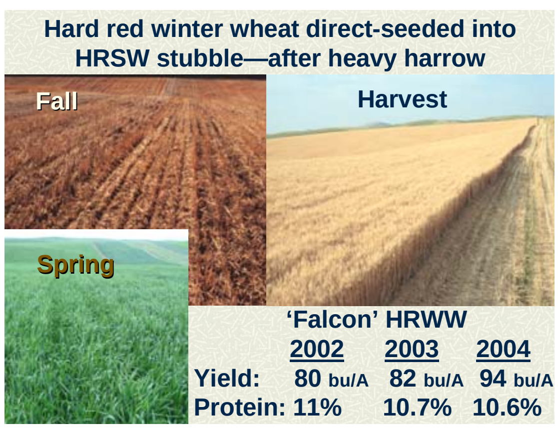



Figure 4.  Yield and protein percentage for hard red winter wheat (HRWW) following hard red spring wheat in 2002-2004.



Figure 5. Direct-seeding winter wheat into spring wheat stubble.

Extended rotation effects on winter wheat yields are also a question of interest. The 2004 growing season provides the first data where the full three-year rotation can be assessed (Figure 6). These results are considered very preliminary as several cycles through a rotation are necessary to assess rotation effects. Nevertheless, the preliminary results are interesting and show possible continued rotation effects of the alternative crops on winter wheat yields. Here, the winter pea-spring wheat-winter wheat rotation averaged at least 10 bu/A greater than rotations with either canola or barley. Research on rotation effects on all crops will continue in the future as a major focus of direct-seed studies at the Cunningham Agronomy Farm.

**Extended Rotation Effects on Winter Wheat??**

| Crop Rotation | 2004 WW Yield |
|---|---|
| WC-SW-WW | 96 bu/A |
| WP-SW-WW | 106 bu/A |
| SB-SW-WW | 93 bu/A |

Figure 6. Preliminary results of rotation effects on winter wheat yields (WW=winter wheat; WC=winter canola; WP=winter peas; SW=spring wheat; SB=spring barley).

The performance of the alternative crops in rotation is also critical. Establishment of winter canola has been difficult due to dry early fall conditions following winter wheat harvest. The dry seed-bed conditions have delayed winter canola establishment and fall growth has been insufficient for the crop to survive the winter. Consequently, we have explored the option of broadcast establishment of Roundup-Ready spring canola on the strip where the winter canola was unsuccessful. Dry fall seed-bed conditions have also delayed the emergence of winter peas and winter barley.  In 2003, stands of winter green peas were insufficient following the winter and spring peas were direct-seeded into the winter wheat stubble.


Figure  7.  Yield of spring canola and spring peas following winter wheat in 2003.  Pictured is applicator used to no-till broadcast spring canola seed.

Comparable yields were achieved for drilled and broadcast spring canola which averaged 1700 lbs/A in 2003.  The broadcast canola was observed to establish less uniformly than the drilled canola which resulted in a wider range of maturity at harvest.  Broadcast spring canola did, however, establish easily in winter wheat stubble which tends to conserve seed-zone water as well as provide protection from spring frosts.  Further ideas for broadcast establishment include earlier spring seeding by either land or air.

In 2004, canola yields were excellent for both drilled and broadcast methods (Figure 10), averaging 2593 lbs/A after winter wheat.  Therefore the two year average for spring canola was 2146 lbs/A.  These results identify small seeded crops such as spring canola and mustard as very promising crops for direct-seeding into winter wheat stubble without burning.  In fact, maintenance of surface residues very likely aids establishment of the crop.

When fall seed-zone water has been sufficient for the early establishment of winter peas, they have performed well.  In 2002, winter peas yielded 2009 lbs/ac an acceptable yield for the “Nutrigreen” variety raised (Figure 8).


Figure 8. Winter peas direct-seeded into winter wheat stubble, 2002 (Dr. Dave Huggins, USDA-ARS pictured).

Winter barley performed well in 2003 and 2004 when direct-seeded into winter wheat stubble (Figures 9 and 10). In 2003, the year that dry conditions limited spring crop yields, winter barley clearly out-performed spring barley. In 2004, under more favorable growing conditions, winter and spring barley yields were more comparable (Figure 10). Disease problems in winter barley including *Rhizoctonia* and stripe rust have impacted yields (see discussion under Objective 4).

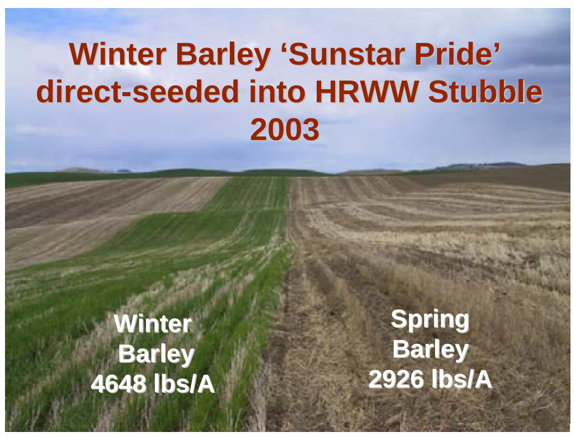



Figure 9. Early spring (2003) picture and grain yield of winter barley (Sunstar Pride) and spring barley (Baronesse) direct-seeded into hard red winter wheat (HRWW) stubble (2002-2003).

**Alternative Crop Performance following Winter Wheat (2004)**

| Direct-Seeded | |
|---|---|
| Spring Canola (Drilled) | 2747 lb/A |
| Spring Canola (Broadcast) | 2439 lb/A |
| Winter Peas | 1329 lb/A |
| Spring Peas | 1946 lb/A |
| Winter Barley | 4314 lb/A |
| Spring Barley | 4797 lb/A |

Figure 10. Yield of direct-seeded alternative crops in 2004 following winter wheat.

Overall, the research results point to the conclusion that crop rotation is a powerful residue management tool in direct-seed systems and can be tailored to achieve both economic and environmental goals. However, further analyses, particularly economic, and growing seasons are required to reach conclusions with sufficient scientific basis to support changes in grower practices and government policy. In other words, these results, although promising, do not supply at this point in time sufficient information to recommend changes in farming practices.

**Objective 2. Determine agronomic benefits, if any, of shortening wheat stubble with or without further spreading, to growth and yield of direct-seeded wheat.**

Methods

Wheat stubble can be managed at or soon after harvest. All harvesting on the CAF for preparation or establishment of the straw management treatments used a JD 6622 combine equipped with the best available technology for chopping straw and spreading chaff, in conjunction with four treatments: (1) normal stubble height (15 inches--control); (2) stubble trimmed and shortened to 6 inches; (3) stubble trimmed to 6 inches, followed by heavy harrow operation; and (4) stubble cut to normal height, followed by a heavy harrow operation (Figure 11). To trim stubble lower than normally achieved with a conventional combine, an extra cutter bar, fabricated by Kile Machine and Manufacturing Inc. of Pine City, WA was mounted on the JD 6622 combine to cut stubble prior to wheel traffic (Figure 12).


Figure 11.  Winter wheat stubble cut at normal height (15 in.), trimmed, or harrowed.


Figure 12.  JD 6622 combine equipped with second sickle-bar.

A 20-ac field at the CAF was used for field studies of stubble management.  The field has been in a 2-year winter wheat/spring wheat rotation for several years, always with soft white varieties, and has been direct-seeded for the past three years.  Geo-referenced points (GPS located) averaging 1 every 100 ft. were used for all sampling and mapping of straw density, crop growth, development and yield.  Four residue management treatments were established across the field.  Each strip was 60 feet wide (the width of the heavy harrow and three times the width of the combine header) and replicated four times.  Because of the irregular field boundaries of the study area, not all straw-management strips were the same length, but each transected south- and north-facing slopes.  All treatments were direct-seeded perpendicular to the residue management treatments with a Great Plains drill.  The drill is equipped with Turbo Coulters™ for fertilizer injection in the front and double disk opens for seed placement at the rear, on 10-inch spacing and aligned so that fertilizer is placed within each seed row below the seed.

Each of the three straw management alternatives to current practice has advantages and disadvantages.  Cutting the stubble short slows the harvesting operation since more straw must pass through the combine.  On the other hand, this method potentially eliminates the need for a heavy harrow with or without the cutter bar. This method also reduces cover for mice and voles that can become serious pests of direct-seeded crops and for which a method of control must be developed.  Use of a heavy harrow is another operation with additional wheel- traffic and potential for soil compaction, and it requires ownership and maintenance of another piece of equipment.  The cutter bar adds still more investment and maintenance expenses, but would allow faster harvest.  The reduction in straw load on the soil surface following the heavy harrow operation not only makes it easier to direct seed winter wheat in the fall, the soil with less residue can be expected to warm faster in the spring, which can help to accelerate growth and development of the winter wheat as it comes out of its dormancy.

Planting winter wheat into any cereal stubble without an intervening fallow or broadleaf crop presents one of the greatest challenges for direct seeding.  This is because the 2 months between harvest (August) and planting winter wheat (October) is too short and conditions are too dry for even the earliest stages of straw decomposition.  By comparison, 8-months between harvest (August) and planting spring wheat (April) is enough time and conditions usually are suitable for considerable weathering and some decomposition before planting, depending on over-winter temperatures.  Even the earliest stages of decomposition and resultant fragile nature of the straw can make it easier to plant into the residue with or without harrowing in the fall.

The disadvantages encountered when planting in the fall into fresh straw can be partially offset by planting winter wheat after spring wheat, since spring wheat produces less straw than winter wheat. Growers in the Palouse region expect to plant at least half of their land in the fall and half in the spring, to spread their work load more evenly between fall and spring.  In addition, direct-seeders commonly prefer more fall- than spring seeding since land in the spring can be soft and more prone to wheel tracks and compaction.

The Haun method was used to document growth and developmental responses of: (1) spring and winter wheat to straw management treatments (Objective 2); (2) winter barley to straw management treatments with and without paired rows (Objective 3); and (3) wheat and barley response to residue management including fumigated and burn treatments (Objective 4).  This method determines the total number of tillers on cereal plants and also which tillers formed or failed to form on plants representative of a given treatment.  This labor-intensive but highly instructive measurement requires evaluation of a representative number of plants for the presence or absence of respective tillers that form if the plant is healthy and unstressed.  The coleoptile tiller (T-O) forms only when growing conditions in the seedbed are ideal.  The T-O is followed, in sequence, by tillers 1, 2, 3, etc., formed in the axils of leaf 1, 2, 3, etc., on the main stem.  Failure of a tiller to form on schedule represents a permanent limitation to yield, since once skipped during plant development, only the next and subsequent tillers in the sequence will form but not those that failed to form when it was their turn.  A high percentage of plants missing tillers 1 and 2, for example, would indicate stressful conditions precisely during the times these tillers were scheduled to form based on accumulated growing degree days.  Without compensatory growth in the form of larger heads or plumper grain, yield is impacted accordingly.

Outcomes

Winter wheat direct-seeded into spring wheat residue showed no difference in growth, development or yield of the wheat in response to the four residue management treatments (Figure 13). Likewise, there were no differences in percentage of roots damaged by *Rhizoctonia* root rot (Figure 13). This means that, with the relatively light load of spring wheat stubble, no further treatment would be necessary. This winter wheat was planted with a cross slot drill so as to maximize any surface residue effects, and still there were no effects. The small percentage of both T-0 and T-1 tillers across all residue management treatments, however, indicates that environmental or biological stresses (e.g. soil-borne disease such as *Rhizoctonia sp*.) occurred early in the establishment of the crop. None of the residue management treatments were able to significantly decrease the apparent stresses. Consequently, although these data show no advantage or disadvantage for direct-seeding winter wheat into the alternative residue management treatments, they do indicate that crop performance was likely compromised by direct-seeding.

**Winter Wheat Development and Yield in Response to Straw Management Alternatives**
**(heavy residue grid points)**

| Response | Straw Management Treatment: Normal | Harrow | H + Trimmed | Cut Short |
|---|---|---|---|---|
| Residue (lbs/A) | 3880 | 4050 | 4360 | 4125 |
| Plants/m$^2$ | 160 | 176 | 165 | 170 |
| Haun | 4.8 | 4.8 | 4.8 | 4.7 |
| % T-0 | 1 | 1 | 0 | 1 |
| % T-1 | 9 | 10 | 12 | 11 |
| % T-2 | 15 | 15 | 15 | 15 |
| % T-3 | 8 | 6 | 6 | 6 |
| % Rhizoc | 24 | 26 | 17 | 22 |
| Yield (bu/ac) | 79a | 75a | 72a | 72a |


Figure 13. Winter wheat growth and development in response to spring wheat straw management alternatives (sampled at multiple points referenced by GPS) in 2003. Note: Haun number refers to the number of leaves on the mainstem. E.g., 4.8 means four leaves fully developed and the fifth leaf 80% developed. Percentage T-0, T-1, T-2 and T-3 refer to the percentage of plants that formed the coleoptile tiller (T-0), and the first, second and third tillers, respectively. Percentage (%) Rhizoc indicates the percentage of seminal roots with *Rhizoctonia* root rot. Picture on right shows no visual response of winter wheat to different residue management treatments established across the field.

In 2004, spring wheat direct-seeded into winter wheat residue showed little response to residue management (Figures 14 and 15). As with the winter wheat results, the residue management treatments had little effect on spring wheat growth, development and yield.

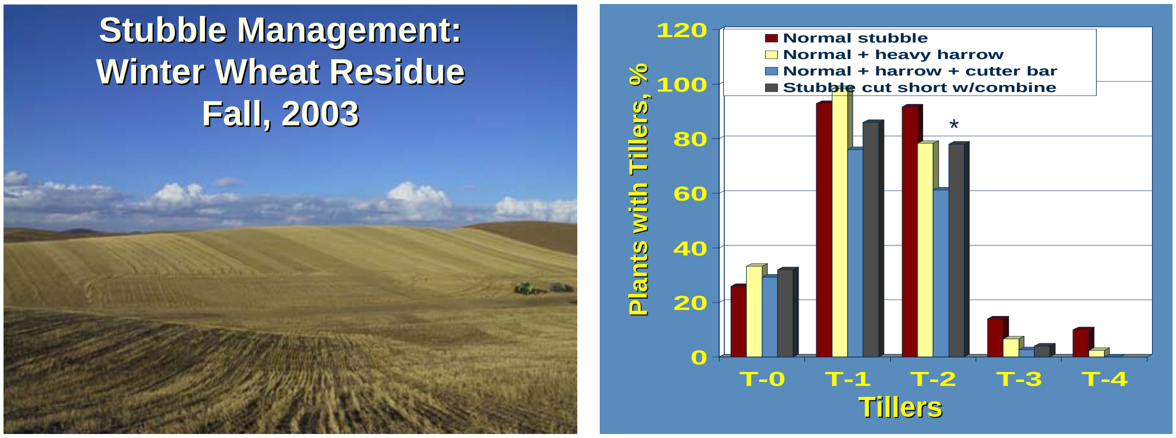



Figure 14. Picture of different residue management treatments (left—far field, fall 2003) and effects on spring wheat tiller formation (right) in 2004.

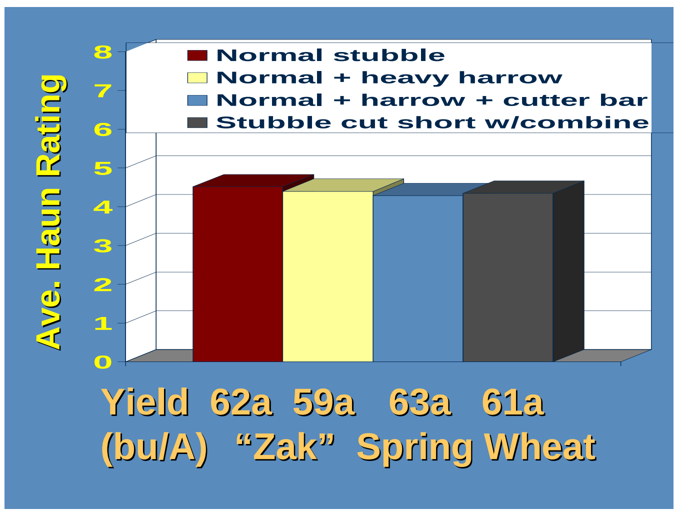



Figure 15. Residue management effects on average Haun rating (mid-spring measurement) and grain yield of spring wheat direct-seeded into winter wheat residues.

**Objective 3. Determine effects of residue management and paired-row spacing as an approach to offset the disease-favoring effects of winter wheat stubble on a fall-sown cereal (winter barley).**

Methods

Winter barley was direct-seeded into winter wheat in the fall of 2002 and 2003. In 2002, residue management treatments consisted of three straw management treatments and two seed-row configurations.

In 2002/2003, we carried out one particularly instructive experiment with winter barley planted into winter wheat straw. This study included six treatments, four representing a small version of the stubble management study detailed in Objective 2 plus a fumigation treatment and a burn treatment (Figure 16).  Each plot was 16 x 24 feet and each treatment was replicated three times.  The six treatments were as follows:

1. Winter wheat stubble cut normal height and spread the full width of the header.
2. As 1., but then trimmed to 6 inches with a mower
3. As 1., but also treated with a small harrow on a three-point hitch to simulate a heavy harrow treatments
4. A combination of 2. and 3. to simulate the trim plus harrow treatment.
5. Normal height but burned and
6. Normal height but fumigated with methyl bromide just prior to planting the winter barley.

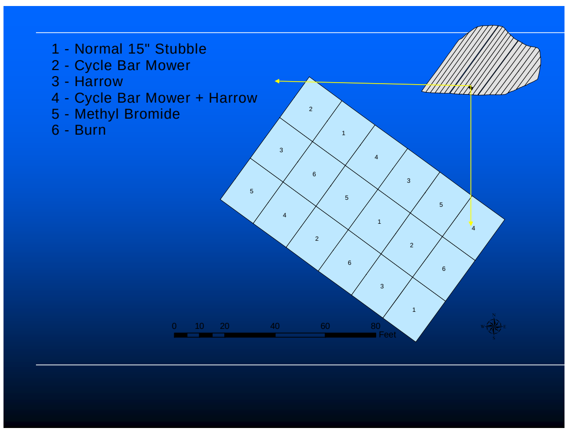



Figure 16.  Residue management treatments and experimental layout for winter barley direct-seeded into winter wheat residue in fall, 2002.

In 2003, the study was a split-plot design with four replications (Figure 17).  Main plots (16 x 60 ft) consisted of seed-row configurations: (1) winter barley planted as 7/17-inch paired-row; and (2) winter barley planted in a 12-inch uniform row spacing.  Subplots (8 x 20 ft) consisted of three residue management treatments: (1) wheat stubble cut at normal height (15 inches); (2) stubble cut at normal height and fall burned; and (3) stubble cut at normal height and fall fumigated.  In paired-row spacing, the crop canopy remains open longer into the season compared with uniform-row spacing, thereby affecting the environment of the top few inches of soil without changing plant density or the number of rows in the field. Earlier studies have shown that paired rows, e.g. pairs 7 inches apart with 17 inches between each pair, results in less damage from root diseases when direct-seeding into stubble than uniform 12 inch rows, but not when direct-seeding into burned or fumigated plots (Cook et al., 2000).  The next step, if necessary, would be to use row cleaners in combination with paired-row spacing.

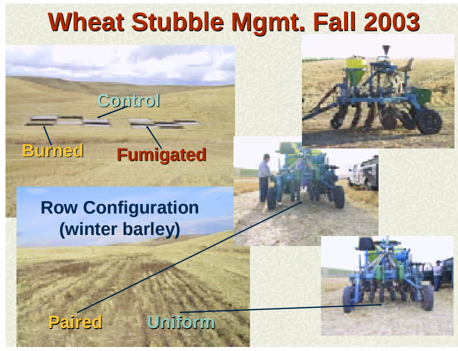



Figure 17. Residue management treatments in winter wheat residue in preparation for fall direct-seeding of winter barley. Significant freezing injury occurred soon after establishment and the plots were discontinued.

<u>Outcomes</u>

Burning the stubble or leaving the stubble untouched but fumigating the plots each resulted in an increase—almost doubling—of both the first and second tillers of winter barley (Figure 18). These two tillers normally rival the mainstem in yield potential and therefore are critical to achieving a high yield. These results point to a stress factor imposed early in the life cycle of the winter barley, probably already while the plants were in the two leaf stage since the message to form or not form the first tiller occurs at this or about the 3-leaf stage of plant development. Grain yield followed a similar response to the residue management treatments (Figure 18). Fumigated, burned and harrow treatments produced the greatest yield; sickle mowing the least yield. These data indicate that further residue management through either row cleaners, greater disturbance during planting (e.g. hoe-type openers) or a paired row configuration could benefit winter barley performance. Unfortunately, the experiment established in the fall of 2003 (Figure 17) was abandoned following severe frost damage.

**Winter Barley Growth and Development in Response to Straw Management Alternatives**

| Response | Straw Management Treatment: Normal | Sickle Mow | Harrow | Burned | Fumigated |
|---|---|---|---|---|---|
| Plants/m$^2$ | 329 | 365 | 412 | 457 | 321 |
| Haun Stage | 3.9 | 3.9 | 3.8 | 4.1 | 3.9 |
| % T-0 | 0 | 0 | 0 | 0 | 0 |
| % T-1 | 23 | 57 | 27 | 60 | 47 |
| % T-2 | 30 | 30 | 23 | 40 | 40 |
| % Rhizoc | 9 | 19 | 3 | 3 | 0 |
| Yield (lb/A) | 5184 | 4717 | 5543 | 5449 | 6129 |
| $LSD_{0.05}$ | bc | c | ab | ab | a |


Figure 18. Winter barley growth, development and yield in response to winter wheat straw management alternatives (small replicated plots). Note: Haun number refers to the number of leaves on the mainstem, e.g., 4.8 means four leaves fully developed and the fifth leaf 80% developed. Percentage T-0, T-1, T-2 and T-3 refer to the percentage of plants that formed the coleoptile tiller (T-0), and the first, second and third tillers, respectively. Percentage (%) Rhizoc indicates the percentage of seminal roots with *Rhizoctonia* root rot. (Dr. R. James Cook, pictured)

**Objective 4. Document effects of cereal straw management and rotation alternatives on root pathogens.**

Methods

Small plots were established in each of four replicate control strips (normal harvest with no additional treatment) of Objective 2 with three treatments: (1) fumigation with methyl bromide; (2) fall burn; and (3) no residue treatment (control). The fumigation and burn treatments were used to estimate the full growth potential of winter wheat and barley (fumigated plots) and the impact of straw residue management on winter wheat and barley growth. Methyl bromide is applied under clear plastic tarp at a rate equivalent to 400 lbs/A. Methyl bromide fumigation has been used routinely in our program for more than 35 years as a tool to estimate the full production capability of wheat with available water and fertility, growing season, and variety in a given field and season. Yields in control plots expressed as a percentage of yield in the corresponding fumigated plots will serve as a measure of the relative root disease pressure on wheat in response to the different straw management treatments. The paired plots will be located to the extent possible over deep soil near a toeslope so as to maximize the yield potential and hence the fumigation response.

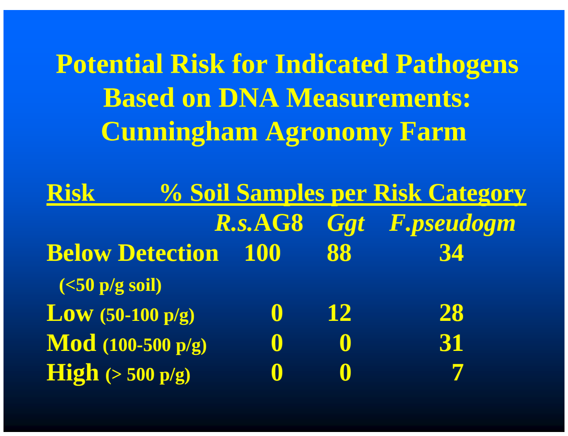

Figure 19. Field establishment of fumigation with methyl bromide, fall burn and no residue treatments. (Ryan Davis, Dave Uberuaga, Shawn Wetterau and Dave Huggins pictured).

As a result of direct-seeding and higher amounts of stubble, some root diseases can become more severe. The lower yields with stubble left standing is due primarily to a complex of root diseases caused by soilborne fungal pathogens. The root diseases are take-all, caused by Gaeummanomyces graminis var. tritici, Rhizoctonia root rot, caused by Rhizoctonia solani AG8 and R. oryzae, Pythium root rot caused by several Pythium species, and Fusarium root and crown rot, cause by Fusarium psuedograminearum and F. culmorum. These pathogens are concentrated in the top 4-6 inches of soil and the pathogens responsible for take-all and Fusarium root and crown rot also live in the bases (crowns) of wheat plants left as stubble in the field. In addition, take-all and Rhizoctonia and Pythium root rots each are favored by cool moist soil conditions typical of the top 4-6 inches of soil under direct seed conditions for both late-planted winter wheat and early planted spring wheat. All research shows to date at the burning does not kill pathogens in the soil, and that the take-all and Fusarium pathogens in tiller bases survive to within ¼ inch of the charred ends of burned stubble. For those root diseases favored by cool moist soil conditions, leaving straw on the soil surface provides the favorable environmental conditions, whereas their activity is greatly limited or virtually arrested by the warmer drier conditions of the top few inches of soil made bare black by burning. Since these pathogens are ubiquitous in the wheat-growing region of eastern Washington and adjacent Idaho and Oregon, being favored by continued presence of wheat and barley host plants, the jincreased yield response can also be expected and demonstrated in virtually any field with heavy straw residues.

In this study, we assessed disease on the rotation, residue and fumigation treatments described in the above section, performed on the Cunningham Farm. Rhizoctonia disease was measured by rating washed root systems, and Fusarium was rated based on the number of infected nodes at the end of the season. The effects of Pythium were indirectly assessed by looking at the fumigation response from methyl bromide. Diseases were also assessed by the Haun rating described above, which is an indication of plant and root health at a particular stage. We also used a DNA method (Ophel-Keller and McKay, 2001) to look at the level of several pathogens in soil across the farm. Unfortunately, this method did not detect the Rhizoctonia and Pythium species present in our area, but did assess take-all and Fusarium

Outcomes

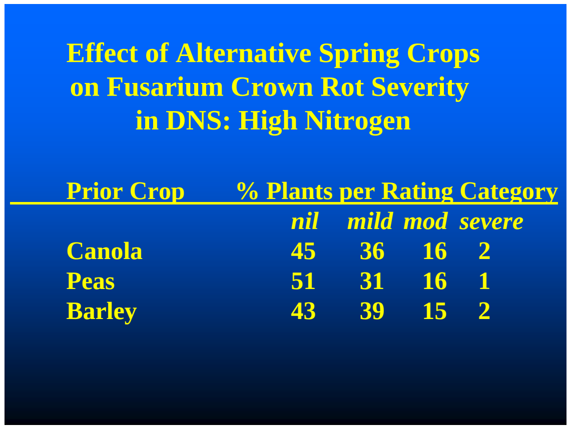
1. Fusarium was present at low to high levels in most sites across the farm. Take-all was virtually absence, mainly because of the 3-year rotation that controls this disease.



**Potential Risk for Indicated Pathogens Based on DNA Measurements: Cunningham Agronomy Farm**

| Risk | % Soil Samples per Risk Category | | |
|---|---|---|---|
| | *R.s.*AG8 | *Ggt* | *F.pseudogm* |
| Below Detection (<50 p/g soil) | 100 | 88 | 34 |
| Low (50-100 p/g) | 0 | 12 | 28 |
| Mod (100-500 p/g) | 0 | 0 | 31 |
| High (> 500 p/g) | 0 | 0 | 7 |


2. Crop rotation did not affect Fusarium disease, because the propagules can survive for long periods of time in the absence of the host. Of the 3 rotation crops, only barley can support Fusarium.



**Effect of Alternative Spring Crops on Fusarium Crown Rot Severity in DNS: High Nitrogen**

| Prior Crop | % Plants per Rating Category | | | |
|---|---|---|---|---|
| | *nil* | *mild* | *mod* | *severe* |
| Canola | 45 | 36 | 16 | 2 |
| Peas | 51 | 31 | 16 | 1 |
| Barley | 43 | 39 | 15 | 2 |

3. There was no effect of stubble management techniques, including burning, on Rhizoctonia (Fig. 18). However, fumigation did eliminate this pathogen. Previous results have shown better plant performance in burned treatments- this may be due to better environmental conditions in the spring (faster soil warming) leading to faster plant development, rather than elimination of the pathogen by soil burning. In addition, Rhizoctonia survives in roots, not crowns, and roots would not be affected by soil burning.

Another series of studies on residue management and diseases was conducted at the Lind Experiment Station, as part of a long-term study in irrigated plots. This project was established in the fall of 2001 with partial funding from the U.S. EPA and involves approximately 10 A devoted to two rotations and three methods of wheat straw management. One rotation/straw management treatment is intended to represent a current practice in parts of the low-precipitation areas of continuous winter wheat irrigated from deep wells with straw burned and the fields moldboard plowed after each harvest in preparation for planting the next crop of winter wheat. The alternative systems uses a 3-year winter wheat/spring barley/winter canola as the main block with three straw management treatments as sub-blocks. The three straw management treatments are no treatment (residue left as spread at harvest), spring barley or winter wheat straw mechanically removed by baling, and straw burned. In each of these straw management treatments, spring barley is the crop planted where the treatments were applied to winter wheat straw, and winter canola is planted where the treatments were applied to spring barley stubble. No residue management treatments are imposed on the winter canola stubble before planting winter wheat. DNA testing was used to establish the effects of the treatments on the pathogen.

*Rhizoctonia*

As expected, *Rhizoctonia* was in higher levels in the treatments that were not tilled, but there was no significant difference among the residue treatments- i.e. burning did not reduce *Rhizoctonia.* It is well known that tillage like moldboard plowing reduces this particular pathogen.

**Effect of Tillage Treatments on DNA levels of of *Rhizoctonia solani* AG-8 in Winter Wheat**

| Treatment | DNA (pg/g soil) | Risk |
|---|---|---|
| *Continuous WW* | | |
| Burn & Plow | 31 A | low |
| *WW/SB/WC/WW* | | |
| Stubble Removed | 80 A | med |
| Stubble Burned | 70 A | med |
| Standing Stubble | 72 A | med |


Take-all
This pathogen was highest in the continuous wheat, even though it had been burned and plowed.  This is because under continuous wheat, this pathogen can build up, but was broken by the barley/canola rotation in the other rotations.

**Effect of Tillage Treatments on DNA Levels of of Take-All Pathogen in Winter Wheat**

| Treatment | DNA (pg/g soil) | Rating |
|---|---|---|
| *Continuous WW* | | |
| Burn & Plow | 30 B | 2.0 A |
| *WW/SB/WC* | | |
| Stubble Removed | 19 AB | 1.1 B |
| Stubble Burned | 21 B | 0.2 C |
| Standing Stubble | 18 AB | 0.2 C |


Fusarium
Fusarium levels were lowest in the two burned treatments, probably due to removal of the crowns.  However, no Fusarium symptoms were seen on the plants, because of adequate water. This disease becomes more severe under drought conditions.  This disease can be managed with nitrogen, by not overfertilizing but using a yield goal tied to potential water.

**Effect of Tillage Treatments on DNA Levels of of *Fusarium pseudograminearum* in Winter Wheat**

| Tillage Treatment | DNA(pg/g soil) | Risk |
|---|---|---|
| *Continuous WW* | | |
| Burn & Plow | 16 AB | low |
| *WW/SB/WC/WW* | | |
| Stubble Removed | 52 AB | med |
| Stubble Burned | 11 A | low |
| Standing Stubble | 83 B | med |

The final take-home message is that burning is not effective in reducing these pathogens by directly killing them. It may improve early growth of seedlings by having warmer soil, but these differences do not result in increased yield. Pathogens are still yield-limiting in our experiments, based on the yield increase seen with soil fumigation. However, there were no consistent differences among the straw management treatments, that could be attributable to an effect on root diseases or pathogens. Most likely, these methods will have an indirect effect on the pathogen by altering the environment of the soil, and making conditions more or less favorable for disease development.

**Objective 5. Convey project findings through print media, conferences and research site tours.**

The combination of realistic large-scale field studies ("seeing is believing") with scientific measurements is a time-proven, successful technique for inducing change in agriculture. The research findings were highlighted by WSU sponsored field-days at the Cunningham Agronomy Farm in 2003 and 2005, articles in Wheat Life and the popular press, numerous tours by WSU classes and small groups and ultimately will be published in peer-reviewed scientific journals.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