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Perennial wheat: The development of a sustainable cropping system for the U.S., Pacific Northwest

by

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Abstract. *Perennial wheat offers a new solution to the long-standing problems of soil erosion and degradation associated with conventional annual small-grain cropping systems in the Pacific Northwest region. Using classical breeding methods, new types of wheat have been developed that maintain the key characteristics of annual wheat, but continue to grow after harvest. Following dormancy in the winter, growth is initiated from the roots or crowns in the spring, allowing a crop to be harvested every fall. By retaining constant soil cover over multiple years, wind and water erosion would be dramatically reduced. In addition, the costs associated with annual seeding and tillage would be minimized, and unlike many reduced tillage systems, it is expected that standard seeding equipment would be suitable for stand establishment. Other potential benefits of perennial wheat include improved wildlife habitat, more efficient use of available water, provision of a potent carbon sink, and the possibility of integrating straw retrieval into a small grains cropping system. Past attempts in the first half of the last century failed to develop perennial wheat as a viable crop, primarily because of low yields, and the research was ultimately abandoned. Perennial wheat production may now be viewed as acceptable for highly erodible land or for obtaining carbon sequestration credits. This paper presents an overview of solutions to the obstacles encountered by previous researchers, introduces some of the newly developed perennial wheat lines, and discusses considerations for management practices.*

Introduction

The area of southeastern Washington and north central Idaho, characterized by rolling hills of deep loess soil and known as the Palouse, is one of the most highly productive wheat *(Triticum aestivum* L.)-growing regions in the world. Yields of wheat for this region typically average 5.4 to 6.7 Mg/ha (80 to 100 bu/ac), compared with 2.0 to 2.7 Mg/ha (30 to 40 bu/ac) in the U.S. Midwest. High yields in this area are attributed to a Mediterranean climate with mild temperatures and over 500 mm average annual precipitation, most of which occurs during the winter and spring months. However, this great productivity does not come without an environmental cost. Estimates of soil loss show that 10% of the cropland in this area has lost all of its original topsoil, and 60% has lost between 25 and 75% of its topsoil since cultivation began in the Palouse little more than a century ago (USDA, 1978). The decline in productivity due to soil erosion has so far been masked by improved wheat varieties and substantial technological inputs (Young et al., 1984). Yields have continued to increase (at a reduced rate) over the last several years, but the long-term health of this system is highly questionable.

The pervasiveness of soil erosion associated with conventional fanning practices and the threat that soil degradation poses to the long-term sustainability of agriculture have been reviewed extensively (Lal, 1998; McCool and Busacca, 1999). Research has demonstrated that soil with a constant cover of plant material is much less prone to erosive forces (Aase et al., 1976). Two main strategies are currently being employed in the Pacific Northwest to gain the erosion-control benefits of constant plant cover: (1) no-till/reduced-till, and (2) the federal Conservation Reserve Program (CRP). However, both of these strategies have inherent limitations. Notill requires expensive, specialized planting equipment and costly herbicide applications, and promotes the development of certain diseases. The CRP is subject to whims of the Congressional budget-making process and interpretations in criteria for classifying land as highly erodible. At Washington State University (WSU), a third strategy is being developed to maximize plant cover for erosion control - the use of perennial wheat as an alternative cropping system.

Perennial wheat would be planted, at least initially, in areas most susceptible to soil erosion (e.g., hilltops, steep slopes, and waterways). Grain would be harvested every year, ideally at the same time as annual wheat. However, instead of employing the potentially destructive practices of plowing or disking, and replanting, the perennial wheat residue and living root structure would remain in the soil, regrowing in the spring to produce another harvestable crop. It is estimated that perennial wheat would need to be replanted once every 3 to 5 years to maintain optimum yields and plant health. By minimizing soil disturbance, significant agronomic and ecological benefits would be realized. One important benefit would be the creation of wildlife habitat. Disruption of nesting birds would occur less often and habitat could be enhanced by not harvesting the grain from perennial wheat in some areas. A patchwork-like landscape would be created if perennial wheat was incorporated into a system with annual grains and CRP, allowing for more buffers and borders, and adding aesthetic value to the land.

Other significant agronomic and ecological benefits of perennial wheat include water and nutrient conservation (Wood et al., 1991), greater soil microbial activity (Blevins, 1984), increased sequestration of carbon (Robertson et al., 2000), and lower time and labor costs. As a result, there would be reduced chemical leaching and surface water pollution, reduced production of greenhouse gases, an overall improvement of soil productivity, and increased biodiversity in the agroecological landscape. These functions, termed ecosystem services, are often overlooked when the land's economic potential is evaluated (Daily et al., 1997). Benefits from a perennial wheat cropping system are more than financial, making it possible to integrate natural capital with economic capital when determining the value of this type of system.

Background

The idea for perennial grain, and wheat in particular, is not new. Russian scientists established large perennial wheat breeding programs, starting in the 1920s (Jakubziner, 1959). In the U.S., Sando of the U.S. Department of Agriculture (USDA) produced hundreds of perennial wheat lines from 1923 to 1935 (Vinall and Hem, 1937, p. 1059). During the 1940s and 1950s, Suneson and Pope at the University of California at Davis bred wheats specifically for perennial habit and found types that yielded within 70% of the best commercial wheats of their time (Suneson, 1959; Suneson and Pope, 1946). They also identified types with resistance to stripe, leaf, and stem rusts, and several root rot diseases. Early efforts in developing perennial wheat were not aimed at reducing erosion, but rather at saving the costs of annual planting, with the main emphasis on high yield. More recent efforts, however, have been directed at the soil conservation benefits of perennial plants (Schultz-Schaeffer, 1970). Schultz-Schaeffer and Haller (1987) released a perennial wheat line derived from the Sando crosses (Vinall and Hem, 1937) that has excellent survivability but very small seed size. Attempts have also been made to establish *Thinopyrum intermedium* (Host) Barknorth & D.R. Dewey, a common source of perennial habit in wheat, as an alternative crop (Wagoner, 1990). At the Rodale Institute, Wagoner (1990) identified variations of desirable traits such as end-use quality, yield, and drought tolerance in accessions of *Th. intermedium.*

Current Research

The perennial wheat breeding program at WSU originated in 1991 when varieties conventionally bred for resistance to Cephalosporium stripe, a prevalent disease of winter wheat, carried not only genes for disease resistance, but also genes for perennial regrowth. Following a review of past research, investigators decided that perennial wheat deserved its own breeding program. The program now includes over 2,000 lines derived from crosses between the most widely grown winter wheats in the Pacific Northwest and perennial wheatgrass species, most from the genus *Thinopyrum.* These species were chosen because of their adaptability, survivability, ease of crossing, disease resistance, yield potential, and threshability (Armstrong, 1945; Fatih, 1986; Jauhar, 1995; Suneson and Pope, 1946). Other perennial donor species are being tested, but have not advanced as far in the program as *Thinopyrum.*

Several hundred crosses have been made during the last 6 years among *Thinopyrum, Thinopyrum*-wheat amphiploids, and annual winter wheat, and evaluated for regrowth in the greenhouse. Some lines are advanced as many as eight generations (BC_2F_6). Advanced lines have been grown in the field since 1998 at three test plot locations in Washington State. The test plot locations, WSU Spillman Farm (Pullman, WA), Schoesler Ranch (Ritzville, WA), and Moore Ranch (Kahlotus, WA), represent three distinct agronomic regions in high, intermediate, and low precipitation areas, respectively. The perennial wheat was seeded in 3.34-m^2 plots in spring or fall at a rate of 120 kg/ha (107 lb/ac) in the high precipitation area and 75 kg/ha (67 lb/ac) in the intermediate and low precipitation areas. Harvest occurred the following August, but was variable for each line and location. Plants were cut with a sickle to a height of about 10 cm, and threshed with a stationary threshing machine.

Promising lines

In August 2000, 530 first-year plots and 35 second-year plots were harvested at the three locations. Of the first-year plots, 152 exhibited vigorous regrowth 6 weeks after harvest, 332 plots exhibited weak regrowth, and 46 plots exhibited no regrowth. Of the 35 second-year plots, 9 exhibited vigorous regrowth, 25 exhibited weak regrowth, and 1 exhibited no regrowth 6 weeks after harvest. Additionally, 372 individual plants were harvested in August 2000. These plants were transplanted from the greenhouse in 1998 and harvested for the second time in 2000 (Fig. 1). Six weeks after harvest, 191 of the plants exhibited vigorous regrowth, 137 exhibited weak regrowth, and 44 exhibited no regrowth.

First-year yields obtained from eight of the most promising lines ranged from 1.688 to 5.775 Mg/ha (25 to 86 bu/ac) (Table 1). By comparison, the most commonly grown annual wheat in the area, Madsen, yielded 8.955 Mg/ha (133 bu/ac). Percentage of plot regrowth in the early fall decreased with increasing yield, ranging from 92% of the lowest yielding lines to 75% of the highest yielding lines. Most lines had an easy to average threshability rating, and normal-looking wheat heads with awns. A normal wheat head, as opposed to the *Thinopyrum*-type head with a longer rachis, may be more desirable for ease of threshability and resistance to shattering. Additionally, the presence of awns may negatively influence the probability of integrating grazers, such as cows or sheep, into a perennial wheat regime. Plant height ranged from 97 to 145 cm, with strong stands and dense crowns. Senescence of these eight lines began 24 July and continued through 21 August, compared with a senescence date of 28 July for Madsen. Five of the most promising lines are segregating, as evidenced by the presence of other head types in the plots. These lines will become more genetically stable with each consecutive generation.

Looking Ahead

Accumulation of seed and data in upcoming years will provide the means to conduct large-scale trials and continue the selection process. In October 2000, 405 plots of advanced lines were planted with seed from first- and second-year plots and second-year field transplants with vigorous fall regrowth. In addition, 107 plots of preliminary lines developed in the greenhouse were planted, resulting in a total of 512 first-year plots, 506 secondyear plots, and 35 third-year plots to be evaluated in 2001. Regrowth of the second- and third-year plots will be measured again in the spring of 2001, providing a more accurate assessment of survivability. During the last 3 years, plots with vigorous regrowth in the fall usually survived the winter; however, winter temperatures during this period were above normal. In addition to survivability, other characteristics being evaluated include growth type (from the crown or rhizomes), crown density, straw strength, tiller number, maturity, plant height, head type, segregation, disease resistance, seed set rate, threshability, yield, and various seed characteristics.

To ensure the best lines are selected under optimum growing conditions, four experiments were established in October 2000 to determine how seeding rate and date, and fertilization rate and date affect perennial regrowth. It is believed that spring seeding, as opposed to fall, the typical time for seeding winter wheat, will produce denser, more uniform stands. Also, for economic reasons, the application of dry fertilizer in the fall may be preferred over spring application. Precipitation throughout the winter will facilitate the movement of fertilizer through the soil profile, placing it within the optimal range for acquisition by roots in the spring. Results of these experiments will not only provide the information needed to improve the breeding program, but also for eventual recommendations to producers. Other management options have been considered, such as integrating a grazer into the system, or intercropping with a legume, as proposed by Wagoner (1990). Experiments with these variables may be conducted in the future, but the initial acceptance of perennial wheat will only be favorable if management practices are similar to those of annual wheat.

Obstacles

Why have past attempts to develop perennial wheat failed to produce varieties that are grown on a commercial scale? Past researchers found that yields were below those of annual wheat, that survivability (stand density) decreased over time, and that perennial lines failed to achieve sufficiently high end-use quality for use as a bread wheat. However, none of these problems are insurmountable for the following reasons:

1. Yield must be viewed in relation to the input costs and the environmental degradation associated with crop production. Acceptable yield is therefore a site-specific determination, dependent, for example, on the erosion potential of the land. Annual plants spend most of their reproductive energy on seed production, whereas perennial plants spend a portion of that energy on developing a vigorous root system. The biological consequence is lower yield, which may be discredited in exchange for the advantages perennial plants provide. Some researchers, however, believe that with the use of advanced breeding methods and proper selection of parents, lower yields of perennial grains may no longer be an inevitable compromise (Moffat, 1996).

2. The choice of the annual and the perennial wheat parents used in previous programs was never optimized. The program at WSU has been working with the most advanced and adapted wheat cultivars in the Pacific Northwest as annual parents, and has begun an ambitious program to screen over 100 accessions from 8 genera of perennial relatives for agronomic potential in terms of yield, disease resistance, phenology, maturity characteristics, grain quality, and survivability.

3. Previous attempts were aimed at developing a perennial hard red wheat, but this level of quality is an inappropriate goal for initial development. Hard red wheat has very strict end-use quality characteristics, such as strong dough and large loaf volume. Soft white wheat has much less strict requirements for end-use quality, which, in general, is easier to breed for than is hard wheat end-use quality (Jones and Cadle, 1997). Therefore, breeding efforts are currently being focused on production of perennial lines with acceptable soft white end-use quality, which is the most important market class in the Pacific Northwest.

4. There has been little basic work done to determine best management practices for perennial wheat. Manipulation of sowing density, fertility management, and planting date has tremendous potential to improve stand establishment, persistence, and ultimately, productivity.

The prevalence of diseases in reduced-till cropping systems presents another challenge to development of perennial wheat. Plant residues left on the soil surface result in higher soil moisture and lower temperatures, conditions that favor soilborne pathogens (Bockus and Shroyer, 1998). However, the species commonly used in conventional breeding programs as sources of disease resistance are the same species currently being used for perennial growth habit. Genes for disease resistance will likely be incorporated into the new varieties along with the genes for perennial growth, while maintaining a high proportion of annual wheat genes. In a recent study, Cox (2000) identified resistance to important diseases of the Pacific Northwest, including wheat streak mosaic, eyespot, and Cephalosporium stripe, among several of the recently developed perennial wheat lines. Disease resistance will continue to be emphasized as an important criterion during the selection process.

Conclusions

Several of the perennial wheat lines under development have considerable promise and are proceeding towards release to farmers in the Pacific Northwest. It is expected that the release of a perennial variety will not occur for several years, due to the extra time required for multi-year selection and evaluation. In the meantime, perennial wheat might be planted for nonproduction purposes, such as in waterways or for wildlife habitat. Following release of a perennial wheat variety in the next decade, producers will be able to realize all of the advantages of perennial wheat, including improved soil, water, and air quality.

Eventually, perennial wheat could be planted on all land used for production, and not just on the areas most prone to erosion. The proposed carbon sequestration payments may give producers an incentive to plant perennial wheat, by supplying them with supplemental income to compensate for lower yields. Looking even farther into the future, it is possible that perennial wheat will be a component of a perennial polyculture, as proposed by Wes Jackson in *New Roots for Agriculture* (Jackson, 1980). This type of agriculture, which is currently being studied at The Land Institute in Salina, Kansas, mimics the structural dynamics of a prairie ecosystem, but involves the use of several perennial, grain-producing species.

In the near future, perennial wheat may be considered as a practical alternative to annual wheat. Research conducted during the last several years has provided very promising results, especially in terms of yield and disease resistance. The problems faced by the development of perennial wheat are not substantially different from those faced by conventional wheat breeding programs. With proper selection of parents and manipulation of management techniques, vigorous healthy stands with yields comparable to annual wheat are possible. The final result will be a cropping system that can help to resolve many of the problems that limit the sustainability of agriculture today.

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