EVALUATING THE ECONOMIC FEASIBILITY OF ENVIRONMENTALLY BENEFICIAL AGRICULTURAL TECHNOLOGIES WITH AN APPLICATION TO PERENNIAL GRAINS

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ABSTRACT

EVALUATING THE ECONOMIC FEASIBILITY OF ENVIRONMENTALLY BENEFICIAL AGRICULTURAL TECHNOLOGIES WITH AN APPLICATION TO PERENNIAL GRAINS

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Many farmers are willing to adopt new technologies only if they are at least as profitable as the ones they replace. For such farmers, an environmentally beneficial technology must offer comparable profitability to that of the established conventional technology. This framework was applied to perennial wheat and intermediate wheatgrass, two environmentally beneficial crops currently under development. None of the perennial grain lines from wheat trials in Australia had profits that were greater than or equal to those of annual wheat, the comparative conventional technology. To be adopted, the lines would thus require a change in price, yield, costs, subsidies or perenniality.

Improvements in grain yield and quality (which influences price) would be the most economically feasible objectives for a plant-breeding program aiming to make perennial grains as profitable as annual wheat. Without subsidies, the perennial grain lines' comparative breakeven grain yields and prices would have to increase by 30 to 14,500 percent for the perennial grain lines to break even with annual wheat. However, soil conservation benefits could justify subsidies of Australian $23 per hectare per year. With these subsidies, the comparative breakeven grain prices and yield gains of the perennial grain lines would be somewhat smaller. So with or without subsidies, significant genetic improvements in grain quality and yield will be required before perennial grains are likely to become as profitable as annual wheat.

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ANR – Annualized Net Return

AVCP – Annual Variable Costs of Production

C Factor – Crop management factor as part of the USLE

CIMMYT – International Maize and Wheat Improvement Center

EB – Environmentally Beneficial

Ha – Hectare

HYV – High Yielding Variety

IRRI – International Rice Research Institute

IWG – Intermediate Wheatgrass

K Factor – Erodibility factor as part of the USLE

KBS – Kellogg Biological Station

Kg – Kilogram

LDC – Less-Developed Country

LS Factor – Slope-length gradient factor as part of the USLE

MSU – Michigan State University

NPV – Net Present Value

NSW – New South Wales, Australia

OREI – Organic Agriculture Research and Extension Initiative

PW – Perennial Wheat

R Factor – Rainfall and runoff factor as part of the USLE

TLI – The Land Institute

USLE – Universal Soil Loss equation

I. INTRODUCTION

Since the mid 1900's, what the public has demanded from agriculture has greatly changed. In the post-World War II era now know as the Green Revolution, the public demanded agricultural technologies that produced high crop yields to help feed a growing global population. However, by the late 1900's, the public began to notice the negative environmental impacts of the high-input Green Revolution technologies, and started to demand agricultural technologies that would do less damage to the environment. Since the public demand for environmentally beneficial agricultural technologies is still growing today, the economic feasibility of the technologies must be evaluated and compared to conventional, high-input technologies.

In order for a profit-maximizing grower to switch from a conventional technology to an environmentally beneficial (EB) technology, the EB technology must have profits that are equal to or greater than the net returns of the conventional technology. In this framework, off-site environmental benefits are considered to be external to the grower's decision-making process unless they directly impact profit. In order for this framework to be correctly applied, a number of assumptions must be made. The most important assumption is that profit is the only characteristic that increases a grower's level of utility. In reality, growers may care about a number of different things beside profit, so other characteristics such as the production of environmental benefits would provide them with utility. However, within the conceptual model given in this thesis, it is assumed that profit is the only characteristic that generates grower utility.

The framework is applied to perennial wheat and intermediate wheatgrass, two environmentally beneficial crops that are currently under development. The profits of the perennial wheat and intermediate wheatgrass lines are compared to the net returns of annual wheat, the comparative conventional technology. The comparative breakeven prices, yields, costs and subsidies that would allow the perennial wheat and intermediate wheatgrass lines to become as profitable as annual wheat are also found. So, to increase the profitability of the perennial wheat and intermediate wheatgrass lines, wheat breeders and geneticists could improve the grain quality to increase the grain price, increase the grain quantity produced at each harvest or allocate subsidy payments to growers of perennial grains. A decrease in the annual variable costs of production or an increase in the perenniality of the lines empirically would not be feasible to increase the profitability of the perennial grain lines.

A benefit transfer study is then conducted to place monetary values on soil erosion reduction, one of the environmental benefits that is expected to be produced by perennial wheat and intermediate wheatgrass. It is expected that both perennial grain crops produce less soil erosion than annual wheat largely because the perennial grains have much larger root systems and hold soil in place better than annual wheat. The case study provided in this thesis takes place in the wheat-growing region of New South Wales, Australia. Soil erosion reduction was chosen as the environmental benefit to be valued monetarily through benefit transfer because soil erosion is an issue in New South Wales. The monetary values for the off-site benefits of reduced erosion are also used as potential subsidy values that could be paid to growers of perennial wheat and intermediate wheatgrass to compensate them for the production of external environmental benefits.

These subsidies are then added to the perennial wheat and intermediate wheatgrass budgets. The inclusion of the subsidy values in the profitability calculations internalizes the environmental benefits that are external to the grower's decision-making process. New comparative breakeven prices, yields and costs that include the subsidies are calculated, and show what changes must be made for the perennial wheat and intermediate wheatgrass lines to become as profitable as annual wheat. The thesis ends with a discussion of how important perenniality is to the profitability of perennial wheat and intermediate wheatgrass, and a conclusion that explains which of the five characteristics, price, costs, yield, subsidies or perenniality, would most feasibly increase the profitability of the perennial grain lines so that they could become as profitable as annual wheat.

II. MOTIVATION OF THESIS

The public's demand for agriculture has greatly changed since the mid 1900's. In the post-World War II era, the public demanded high-yielding agricultural technologies that could help alleviate worldwide hunger issues. This demand brought about the Green Revolution, where high-yielding varieties (HYV's) of maize, wheat and rice were developed and implemented in developed and less-developed countries (LDC's). Along with HYV's, input packages made of fertilizer, pesticides and mechanization were also developed to increase the yields of the new plant varieties. Shortly after the implementation of the HYV's and input packages, the public began to notice the negative environmental impacts that were generated by the productivity-oriented technologies.

Once the public became aware of these negative environmental impacts, what they demanded from agriculture began to change. The first Earth Day was held in the U.S. in 1970 in response to the public's anger over environmental pollution. Afterward, 'alternative' agricultural technologies that were less environmentally damaging than intensive, conventional agriculture started to be developed (Beus and Dunlap 1990). The alternative agriculture movement gained strength in the 1980's, and the demand for environmentally beneficial (EB) agricultural technologies has been growing ever since. Many members of the U.S. public now demand agricultural technologies that produce crops organically, use lower levels of inputs or mechanization or provide environmental benefits. Conventional and EB agricultural technologies both generate very different private and public benefits and costs. Although alleviating hunger is still a key issue, utilizing agricultural technologies that produce relatively high yields while also generating lower amounts of environmental damage is important to the U.S. public.

2.1 The Green Revolution

History of Productivity-Oriented Technologies

Productivity-oriented agricultural technology breakthroughs largely began in the U.S. in the post World War II era prior to the Green Revolution. Following World War II, agricultural mechanization and chemical inputs (fertilizers and pesticides) became increasingly available to farmers in the U.S. and abroad (Dimitri et al. 2005). Many farmers began to adopt these productivity-oriented technologies in response to the increased availability of the technologies and their decreased costs. Shortly after the increased availability of mechanization and chemical inputs came the development of high-yielding wheat, rice, and maize varieties along with the increased use of irrigation, which is now known as the 'Green Revolution' (Evenson and Gollin 2003).

High-yielding maize and wheat varieties were first bred in the 1940's at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico. Production of these crops boomed in Mexico and many other countries after the advent of the first crop varieties, and continued to increase for decades after (Sonnenfeld 1992). Shortly after the creation of the HYV's at the CIMMYT, researchers at the International Rice Research Institute (IRRI) in the Philippines began to breed high-yielding rice varieties in response to a decrease in available agricultural land and an increase in population in the Philippines. The rice varieties created by the IRRI were quickly adopted in numerous other LDC's in Asia and elsewhere (Hayami, David, Flores, and Kikuchi 1976).

After the release of HYV's from the CIMMYT and IRRI, the yields of wheat, maize and rice grew worldwide. Between 1960 and 1990, the grain yields of high-yielding wheat varieties alone increased between two and three times of what the yields were before 1960

(Khush 1999). The original HYV's were often adapted to fit local environments, and by the early 1970's original HYV's or locally adapted ones were cultivated across the globe (Dalrymple 1979). The HYV's were adopted in developed countries as well as in less developed countries. In the United States, the grain yields of maize and wheat greatly increased due to the implementation of HYV's and HYV packages. In LDC's, by 1979 more than a third of the wheat and rice plants were IRRI, CIMMYT, or locally-adapted HYV's (Dalrymple 1979).

HYV Attributes

To attain such high yields, certain genetic traits were bred into the HYV's during the Green Revolution. These genetic traits consisted of two main groups: dwarfing genes that caused the HYV's to be much shorter than traditional varieties, and genes that made the HYV's resistant to specific diseases and pathogens. The semi-dwarf genes caused plants to be resistant to lodging, to have shorter and stronger stems and to increase grain yield while decreasing straw biomass (Hedden 2003). Semi-dwarf varieties were created for both wheat and rice during the Green Revolution, and generated much higher grain yields than non-dwarf varieties.

Genes that caused crops to be resistant to pathogens and diseases were also bred into the high-yielding varieties of the Green Revolution, and helped to increase the grain yields produced by the HYV's. With the start of the Green Revolution came large waves of monoculture; in many areas of the world, only one variety of a crop was grown over large plots of land. Monoculture often led to an increased incidence of pests and diseases, so breeders developed HYV's that were resistant to some diseases and pathogens in order to counteract this and to fend off any potential crop disease epidemics (Matson et al. 1997).

Over the course of the Green Revolution, "breeders had been successful at improving resistances to abiotic stresses, pathogens and diseases, and at deploying these defenses in space and time so as to maintain yield stability despite low crop diversity in continuous cereal systems" (Tilman et al. 2002). Consequently, HYV's produced increased grain yields because of genetic sources of resistance to diseases and pests, and because of semi-dwarf genes that decreased lodging and redistributed biomass from stems to grain.

HYV Crop Packages

High-input crop packages were developed before and during the Green Revolution to increase the yields of wheat, maize and rice. The main focus of the Green Revolution was to increase the yield of staple food crops without having to greatly expand the area of cultivated land. This goal was not accomplished through the creation of HYV's alone; crop 'packages' that consisted of HYV's, fertilizers, pesticides, mechanization and access to water resources through irrigation led to the high yields experienced during the Green Revolution (Matson et al. 1997 and Pinstrup-Andersen and Hazell 1985). These crop packages made up what is now known as 'intensive' agriculture. Throughout this paper, when the term 'conventional' is used, it refers to the intensive agricultural technologies that were developed before and during the Green Revolution. The HYV packages implemented through conventional agriculture greatly increased the yields of many crops worldwide, and helped to feed the growing populations of LDC's.

2.2 Development of Environmentally Beneficial Agriculture

Technologies that were developed and implemented during the Green Revolution had a number of damaging impacts on the environment. The negative impacts generated demands for agricultural technologies that would do less environmental damage or that would produce environmental benefits. Although the public still demands crop varieties that have high grain yields, the environmental impacts of agricultural technologies are of great concern to many people in the U.S. and abroad today.

Concerns over the environmental impacts of conventional agriculture came about almost as soon as the Green Revolution technologies were developed. Fear over pesticide use and compromised water quality became widespread at the start of the second half of the 1900's (Lutts 1985). However, the main demand for less damaging and environmentally beneficial agricultural technologies really began in the 1980's with the development of the idea of 'alternative agriculture' (Beus and Dunlap 1990). The demand for less environmentally damaging agricultural technologies continued to grow after the 1980's when the concept of alternative agriculture morphed into conservation and sustainable agriculture. The demand for environmentally beneficial and less environmentally damaging agricultural technologies continues to grow today as growers implement technologies like conservation tillage and organic growth systems, and as numerous research institutions develop agricultural technologies that provide benefits to the environment.

Environmental Impacts of Conventional Agriculture

The HYV packages developed during the Green Revolution included numerous inputs such as fertilizers, pesticides, irrigation and machinery. Along with increasing crop yields, these crop packages generated a large number of negative environmental impacts. Algal blooms from the leaching of different types of fertilizer, soil erosion, decreased soil quality and fertility, water scarcity, decreased water quality (due to pesticides, fertilizer and soil erosion) and increased resistance of pests to pesticides were all attributed to intensive agriculture (Pimentel and Pimentel 1990). Loss of biodiversity and decreases in ecosystem health due to pesticide use were two other environmental impacts of the productivity-oriented technologies (Tilman et al. 2002). These impacts exemplified how conventional agricultural practices reduced the quality and health of the environment, specifically after the advent of the Green Revolution (Matson et al. 1997). After the development of Green Revolution technologies, the U.S. public believed (and still believes today) that the negative impacts of conventional agriculture compromise environmental and human health. This generated demand for EB agricultural technologies that continues to grow today.

History of Environmentally Beneficial Agriculture

At first, the sustainability and stability of the growths in crop yield were not considered, and neither were the potential environmental impacts of the Green Revolution technologies (Conway and Barbier 1990). However, as the environmental impacts of the HYV packages became better known, the public's agricultural demands began to change in the U.S. and abroad. The public began to notice the environmental impacts of intensive agriculture in the 1960's, initially due to the popularity of Rachel Carson's *Silent Spring*, which described the impact of pesticides on environmental health (Lutts 1985). In discussing the impact of *Silent Spring*, Ralph Lutts claims that "never before had so diverse a body of people, from bird watchers, to wildlife managers and public health professionals, to suburban homeowners been joined together to deal with a common national and international environment threat" (1985). *Silent Spring* led to increased fear over pesticide use and water quality, which brought about the very first Earth Day celebration, which was held in 1970 (Freeman 2002). Even though the public began to notice the environmental impacts caused by conventional agriculture in the 1960's and 70's in the developed world, food shortages in LDC's led to the continued focus on the production of staple food crops. It was not until the 1980's, when the rates of crop production growth began to slow down, that the U.S. public began to seriously consider the environmental impacts of Green Revolution technologies, and started to demand agricultural technologies that produced environmental benefits (Tilman 1998).

In the early 1980's, 'alternative' agricultural technologies began to be developed in the United States. These alternative technologies focused on using lower amounts of inputs in the growth of staple food crops, and on the interaction between ecology and agriculture (Beus and Dunlap 1990). Some of the first alternative agricultural practices were conservation tillage, integrated pest management and drip irrigation (Tilman et al. 2002). In the 1980's, these practices were mainly cultivated in response to the public's unhappiness with the environmental impacts of HYV packages, the slowdown in the growth rate of crop production and the disappearance of small farmers that could not afford Green Revolution technologies (Beus and Dunlap 1990). The idea of alternative agriculture spread, and began to represent all agricultural practices that generated less environmental damage.

The term 'sustainable agriculture' was first published in 1980 in Wes Jackson's *New Roots for Agriculture*, and was used throughout the world by 1987 (Gold 2009, and Edwards et al. 1990). At the same time, conservation practices such as conservation tillage became increasingly popular, and by the early 1990's agricultural conservation practices became widespread among growers. According to Bob Holmes in 1993, "very few of them (farmers) plow anymore. Conservation tillage and cutting back on chemical use have become bragging points in coffee shops." The implementation of conservation practices has continued to increase since the early 1990's. Today in Michigan, almost all of the state's wheat growers employ conservation tillage, even those that consider themselves to be conventional growers. EB technologies have thus infiltrated numerous agricultural systems in the U.S. and abroad.

Environmentally Beneficial Technologies

Today there are a large number of agricultural technologies that provide less environmental damage or generate environmental benefits. Some of these technologies are crop rotation, intercropping, drip or pivot irrigation, reduced tillage, cover crops and balanced fertilizer use (Tilman et al. 2002). Organic agriculture is another practice that has gained increasing popularity in the last decade, and provides a much lower environmental impact than conventional agriculture. Organic agricultural practices are now used across the globe in many developed and developing countries, and are thus some of the most widely used environmentally beneficial technologies (Weidmann et al. 2009).

The case study provided in this paper showcases an environmentally beneficial agricultural technology that is currently under development. The case study describes perennial wheat and intermediate wheatgrass, two crops that are expected to provide a number of environmental benefits such as reduced nitrate leaching, greenhouse gas sequestration and decreased soil erosion due to the crops' complex root systems and perennial nature (Glover et al. 2010). Many environmentally beneficial agricultural technologies like perennial wheat and intermediate wheatgrass are being developed today because of the increased demand for EB agricultural technologies that came about from the negative environmental impacts caused by Green Revolution technologies.

2.3 Conclusion

The public's expectations of agriculture have greatly changed since the mid 1900's in the U.S. and abroad. In the mid 1900's, productivity-enhancing technologies were generated in response to the demand for higher crop yields to help alleviate global hunger issues. However, once the public began to notice the negative environmental impacts that the Green Revolution technologies generated, their demands began to change. With the advent of alternative, conservation and sustainable agriculture in the 1980's, the public began to demand agricultural technologies that generated lower levels of environmental damage. Today, the public still demands relatively high-yielding technologies, but they also want agricultural technologies that produce environmental benefits instead of environmental damages. Because of this, a number of environmentally beneficial and less environmentally damaging agricultural technologies currently exist or are under development.

III. CONCEPTUAL MODEL

Since the agricultural demands of the U.S. public have largely changed from being productivity oriented in the mid 1900's to environmentally oriented today, the economic feasibility of environmentally beneficial agricultural technologies should be assessed. The conceptual model developed in this section evaluates how the profitability of EB technologies compares to that of conventional technologies. An increase in farm profit (regardless of the type of agricultural technology that is implemented) increases the budget available for consumption, and utility increases in consumption. Consequently, it can be assumed that profit indirectly generates grower utility. Indeed, for many growers, utility is a lexicographic function of profit, with environmental benefits desirable only if they involve no sacrifice of profit (Knowler and Bradshaw 2007).

In order to implement the conceptual model, it is assumed that grower utility is a lexicographic function of profit and environmental benefits, where profit is maximized first. In reality, growers care about a number of different characteristics such as the production of environmental benefits. In the real world these other characteristics may increase a grower's utility, but in this conceptual model it is assumed that profit is the most important characteristic to grower utility maximization. So, through the conceptual model environmental benefits are external to a grower's decision-making process unless they directly impact profit. Consequently, particularly for understanding the potential for farmer adoption of a new EB agricultural technology, profitability is a precondition for adoption and utility maximization. The conceptual model thus shows how a grower can maximize profit when switching from a conventional technology to an environmentally beneficial agricultural technology, assuming that off-site environmental benefits are externalities.

3.1 Development of the Conceptual Model

Within the conceptual model, an EB technology is at least as profitable as a conventional technology if the profits of the EB technology are equal to the net returns of the conventional technology. The profit of the EB technology is based on crop yield, crop price, unit costs and any subsidies paid to the grower for producing environmental benefits. Providing subsidies for off-farm environmental benefits is a way to internalize the externalities. With a subsidy, the off-site environmental benefits would become internal to the grower's decision-making process because the environmental benefits' subsidies would increase the grower's profits. However, without subsidies, the environmental benefits would remain external to the grower's decisions. So, if the profit of the EB technology is smaller than the net returns of the conventional technology, the EB crop price or yield must increase, the unit costs must decrease or a subsidy payment must be added in order for the grower to adopt the EB technology.

A few assumptions are necessary for the application of the conceptual model. The first and most important assumption is that the grower's objective is to maximize profit when switching from a conventional technology to an EB technology. It is assumed that profit, through consumption, is the only characteristic that increases utility, even though many other characteristics may actually maximize grower utility in the real world. Second, the profit of the EB technology must only be compared to that of the conventional technology and not to the profit of any other farm practice. A suitable conventional technology for comparison to an EB technology can be chosen by determining which conventional technology is the most similar to the EB technology. Accordingly, the conceptual model describes a two-way comparison of the EB technology and the conventional technology only. Third, the crop yields of the EB technology and the conventional technology must come from two separate production functions. Fourth, prices p_N and p_0 do not have to be equal, but they do have to be constant. If these prices were to change, the conceptual model would become considerably more complex to account for the changes. Finally, the grower cannot receive a subsidy when implementing the conventional agricultural technology, only when implementing the EB technology. Given these assumptions, the conceptual model is:

$$\begin{aligned}
&\text{Max } \pi_N \\
&\text{s.t. } \pi_N = (p_N \cdot y_N) - c_N + \sigma_N \\
&\qquad \pi_N \geq NR_0 \\
&\qquad NR_0 = (p_0 \cdot y_0) - c_0
\end{aligned}$$

Where:
π_N= profit of the environmentally beneficial technology
p_N= price of the EB crop
y_N= yield of the EB crop
c_N= unit cost of the EB crop
σ_N= per-unit subsidy paid to the grower of the EB crop
NR_0= net return of the conventional crop
p_0= price of the conventional crop
y_0= yield of the conventional crop
c_0= unit cost of the conventional crop

The focus of the empirical analysis is thus to find the level of price, yield, cost or subsidy payment of the environmentally beneficial crop that would make its profit at least equal to the net returns of the conventional crop. If π_N was not greater than or equal to

NR_0, the EB technology would not be adopted as is, and the price, yield or subsidy payments of the EB crop would need to increase, or the costs of the EB crop would need to decrease for adoption. If this were to occur, the EB technology would become as profitable as the conventional crop. A discussion of how these changes would impact the profitability of an environmentally beneficial technology is given below.

3.2 The Net Return Threshold

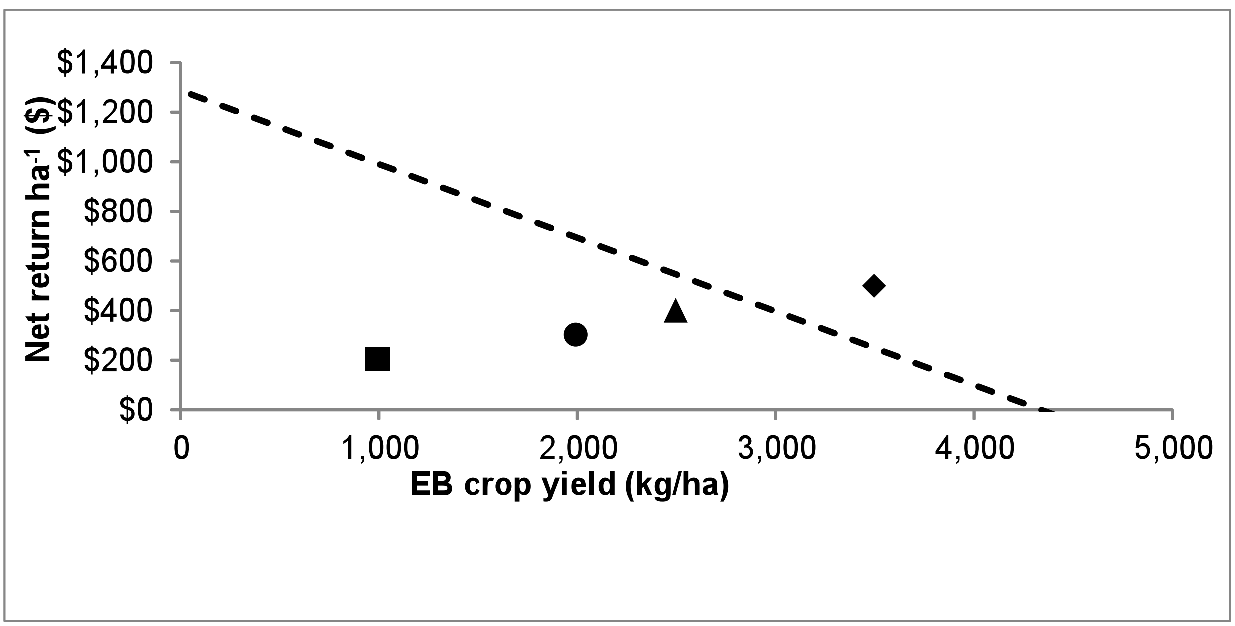
In order for the environmentally beneficial technology to be at least as profitable as the conventional technology, the profit of the EB crop must be equal to the net returns of the conventional crop. This idea can be illustrated graphically as a net return threshold. Given the yield of the EB crop, the net return threshold is the EB crop's level of profit (π_N) that is equal to the net returns of the conventional crop (NR_0). In equation form, the net return threshold is:

$$(p_N \cdot y_N) - c_N + \sigma_N \geq NR_0 \qquad (1)$$

In equation 1, p_N, y_N, c_N and σ_N are the price, yield, unit cost and subsidy payments of the EB crop, and NR_0 is the net return of the conventional crop. The net return threshold thus determines what price, yield, cost or subsidy changes must occur for the profit of the EB crop to be equal to or greater than the net return of the conventional crop. So, the net return threshold is the level of profit that the EB crop must produce for the EB crop to be at least as profitable as the conventional crop. A graphical representation of the net return threshold is provided below in figure 3.2.1.

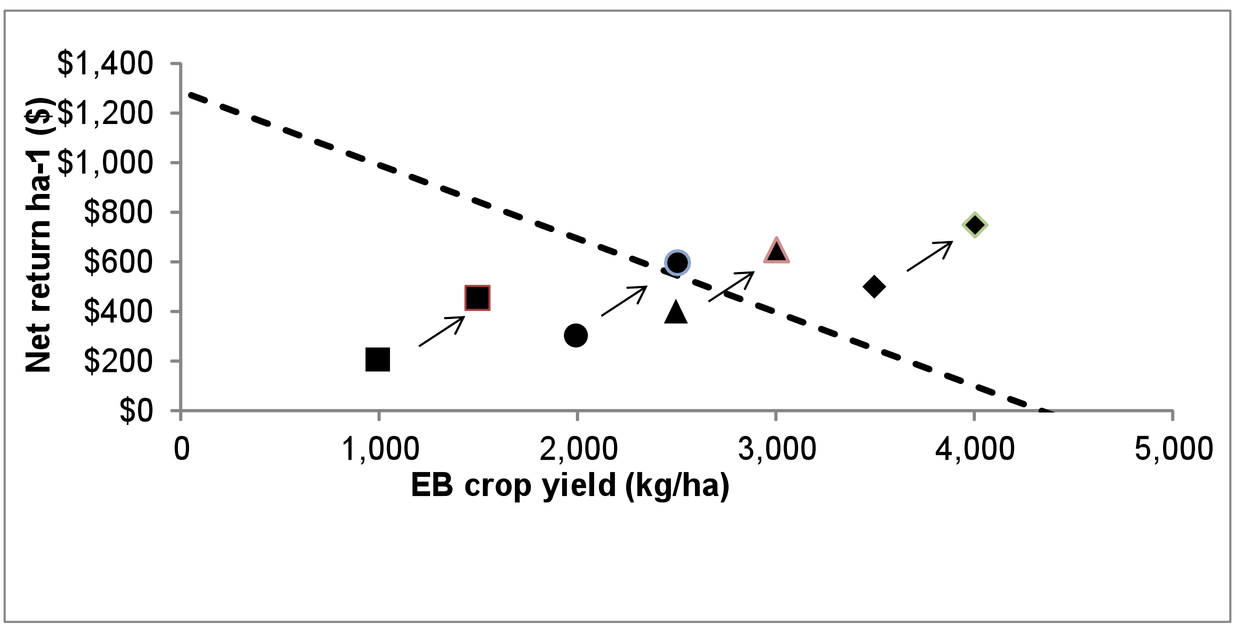
In the net return threshold graph, the dotted line represents the net return threshold. The net return threshold is downward sloping because as the yield of the EB crop grows, it becomes more likely that the EB crop will have profits that equal the net return of the conventional crop. Within the graph, the four shape points are four different varieties of the same environmentally beneficial crop. The graph does not include data from a specific crop; the name 'EB crop' is used to represent any type of crop that would come from an environmentally beneficial technology. Although the conceptual model is applied to a specific EB crop later on in this thesis, the graphs below do not represent the net returns or yields of that crop. Each shape point in the graph provides the profit of an EB crop variety, given a specific yield. Since three of the shape points are below the net return threshold, a change in crop price, yield, cost or subsidy payment would be necessary for any of the three varieties to reach the net return threshold. If these changes were to occur, more varieties of the EB crop would become as profitable as the conventional crop because the profit of the EB crop varieties would equal the net return threshold.

Figure 3.2.1 Net Return Threshold



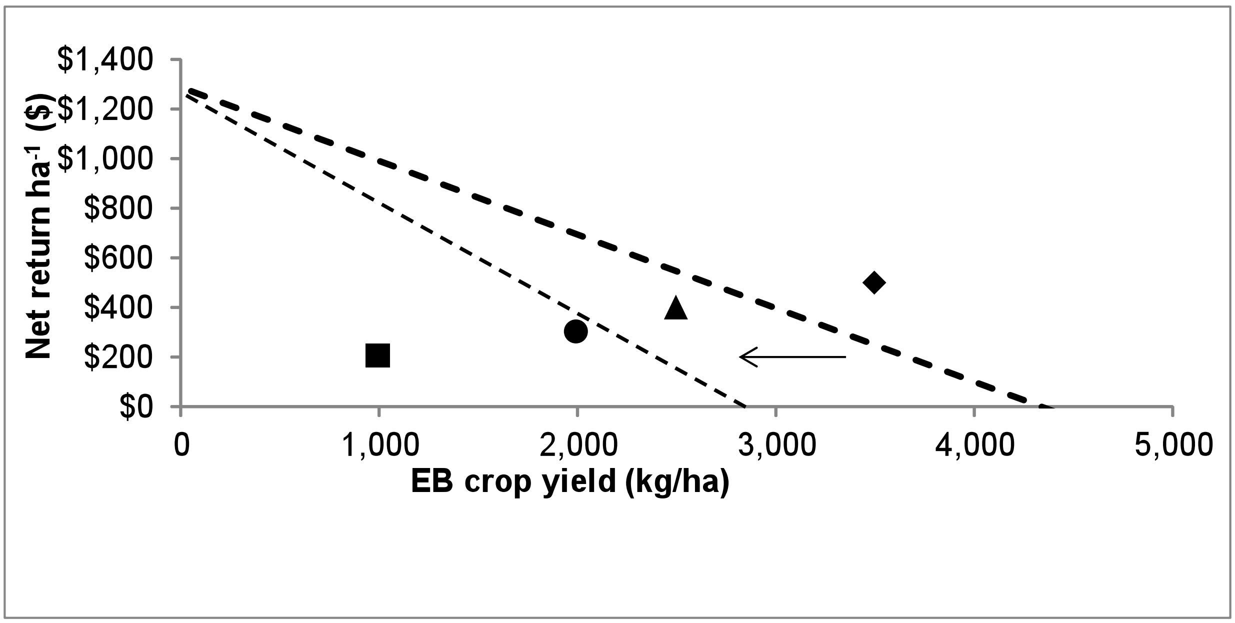
When a component of the conceptual model changes (such as an increase in crop yield), part of the graph shifts or pivots to reflect those changes. If an EB crop variety were to be below the net return threshold, an increase in price, yield or subsidy, or a decrease in cost, could cause the profit of the EB technology to equal the net return of the conventional technology, thereby allowing the EB crop to become as profitable as the conventional crop. An increase in the yield of an individual crop variety would shift one of the shape points right, along the x-axis, because the x-axis contains the EB crop yields. Since the profit would also grow with an increase in yield, the shape point would move upwards along the y-axis in addition to moving rightward. The graphical changes caused by an increase in the crop yield of the four varieties are shown in figure 3.2.2 below. The graph shows that an increase in the yield of the four EB crop varieties would cause the shape points to shift right and move upwards. A decrease in crop yield would have the opposite effect, and would not allow the EB crop to become as profitable as the conventional crop.

Figure 3.2.2 NR Threshold, Yield Increase



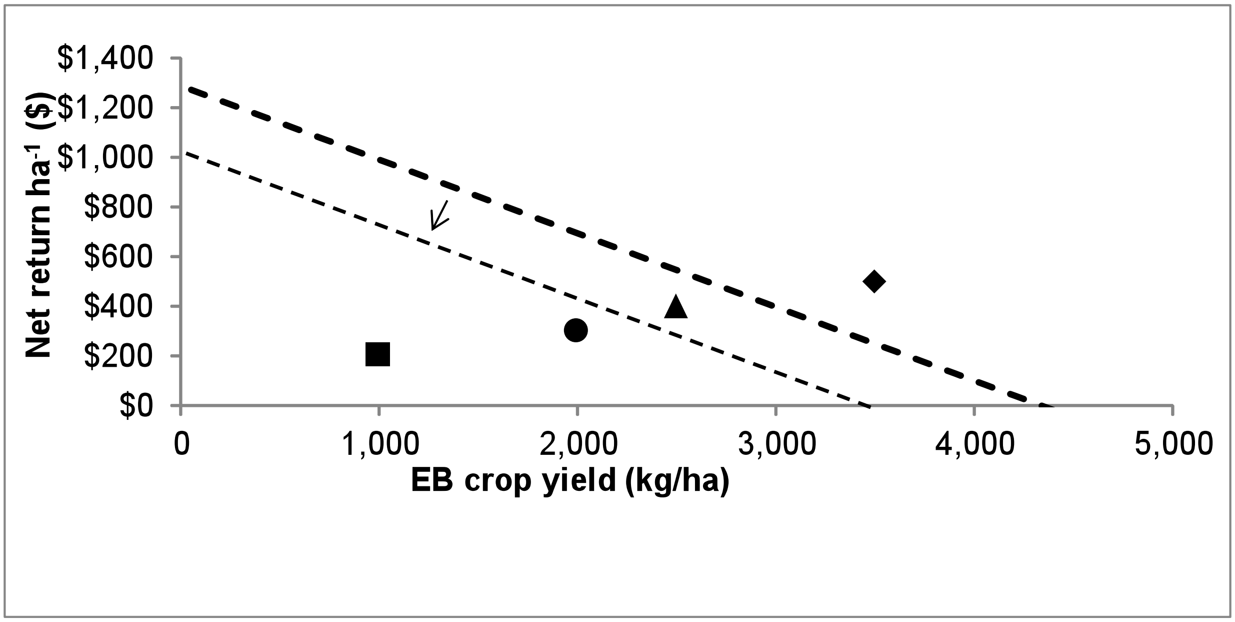
Changes in the other components of the conceptual model also generate graphical movements. An increase in the price of the crop would rotate the net return threshold curve downward toward the origin. The pivoting of the threshold curve would thus decrease the crop yield that would be necessary for the EB crop to reach the net return threshold. The graphical interpretation of an increase in price is given in figure 3.2.3 below. In this graph, an additional EB crop variety becomes as profitable as the conventional crop because of the increase in crop price and the subsequent pivot of the net return threshold curve.

Figure 3.2.3 NR Threshold, Price Increase



A decrease in the costs of production or an increase in subsidy payments would shift the net return threshold curve downwards, closer to the origin. Both changes would have the same graphical movement. The parallel downward shift would decrease the price and yield that would be necessary for the crop varieties to meet the net return threshold. The graphical impact of a decrease in cost or an increase in subsidy payments is provided in figure 3.2.4 below. Again, another EB crop variety would become as profitable as the conventional crop due to the shift in the net return threshold curve.

Figure 3.2.4 NR Threshold, Cost Decrease or Subsidy Increase



Within the conceptual model and the net return threshold, the addition of a subsidy payment is a way to internalize the external environmental benefits provided by an EB crop. Since utility is a lexicographic function of profit, a grower would not be willing to give up profit to gain external environmental benefits. The only way to internalize the environmental benefits produced by EB crops would be to have the environmental benefits directly impact profit. Providing a grower with a subsidy payment for the production of external environmental benefits would thus internalize the externalities, since the subsidy payment would directly influence the grower's profit. Throughout the empirical application of the conceptual model given in the next chapter, it is important to remember that if the EB crop's environmental benefits do not directly impact profit in some way, they are external to the conceptual model and the grower's decision-making process.

3.3 Conclusion

The conceptual model described here explains that the profit of an EB technology must be greater than or equal to the net returns of the conventional technology in order for the EB technology to be adopted, given a number of assumptions. Since it is assumed that utility is a lexicographic function of profit, a grower would not adopt an EB technology if it produced a lower level of profit than the conventional technology. The environmental benefits provided by an EB technology are thus external to the grower's decision-making process and the conceptual model unless they directly impact profit. It is assumed that a grower would not take environmental benefits into account when switching agricultural technologies unless the environmental benefits become internalized, such as through the inclusion of subsidy payments.

IV. BREAKEVEN ANALYSIS OF PERENNIAL WHEAT AND INTERMEDIATE WHEATGRASS

Perennial wheat and intermediate wheatgrass are two new perennial grain crops that are expected to offer environmental benefits, and are being studied in the U.S. and abroad. The main environmental benefits that perennial grains are expected to offer are greenhouse gas sequestration, reduced soil erosion and decreased nitrate leaching (Glover et al. 2010). This study applies the conceptual model developed above to the growth of perennial wheat and intermediate wheatgrass. In this case, annual wheat is considered to be the conventional agricultural technology while the perennial grains are the environmentally beneficial agricultural technologies. The profits of the technologies are evaluated and the changes in price, yield, subsidy payments and costs that would allow the perennial grains to become as profitable as annual wheat are found.

Before now, only two studies had been developed that discuss the economic feasibility of the growth of perennial wheat and intermediate wheatgrass. In 1989 Dave Watt described theoretical breakeven prices and grain yields of intermediate wheatgrass, and in 2008 Lindsay Bell et al. evaluated the potential economic viability of perennial wheat in Australia. Neither of these studies compared expected profits of perennial grain lines to the potential annual net returns of annual wheat. The results of this study are significant because they are the first of their kind. Through the application of the conceptual model, the potential profits of the perennial grain lines given the actual grain yields are compared to the net returns that would be generated by the growth and harvest of an annual wheat line. Besides evaluating the profitability of perennial wheat and intermediate wheatgrass, this chapter also provides a literature review that describes the background information and history of the development of both crops.

4.1 Literature Review

The purpose of this literature review is to describe the attributes of perennial wheat and intermediate wheatgrass and the history of both crops' development. Perennial grains here attracted interest because they both produce wheat grain and environmental benefits while only requiring low levels of inputs. These factors have motivated the development of perennial grains since they were first grown in the 1920's. Even though both crops have been in development for almost a century, not a lot of funding was given to perennial grain experiments in the past. So, perennial grains are still at an experimental stage today and not yet commercially viable. However, since a number of institutions are researching them in different countries, commercially viable perennial wheat and intermediate wheatgrass lines could become available in the future.

Background Information

Perennial wheat was created by crossing a wheat, *Triticum aestivum*, with a perennial grass, *Agropyron elongatum* (Scheinost et al. 2001). Wheat plants are annual, meaning that they must be replanted after harvest every year, while some grasses are perennial, meaning that they grow for numerous years without needing to be replanted (Lammer et al. 2004). The cross between a wheat and a grass created a wheat crop with a perennial habit, called perennial wheat. Intermediate wheatgrass is similar to perennial wheat, but it was not formed by crossing a wheat with a grass. Intermediate wheatgrass, or *Thinopyrum intermedium*, is a perennial grass that may produce larger amounts of seeds than other grasses (Barkworth and Dewey 2005). Consequently, intermediate wheatgrass has more grass characteristics than wheat, while perennial wheat has more wheat characteristics than grass. Theoretically, both perennial grain crops can live from 3 to 5 years before they need to be replanted (Lammer et al. 2004).

One of the main reasons for the development of perennial grains is that their growth does not require much tillage (Moffat 1996). The growth of annual wheat requires that seeds be planted every year. Because of this continual replanting, annual wheat requires much more tillage than perennial grains, which only require tillage every 3 to 5 years when seeds are planted, depending on how long the wheat lines survive. Since monetary and environmental costs are associated with tillage, perennial wheat and intermediate wheatgrass can be much less costly than that of annual wheat for the environment and for growers.

It is also expected that perennial grains can provide several ecosystem services and environmental benefits. It is expected that one of perennial wheat's main environmental benefits is soil erosion control. Since farmland that grows perennial grains only needs to be tilled once every few years during seed planting, perennial wheat and intermediate wheatgrass should cause less soil erosion than annual wheat (Moffat 1996). Erosion may also be decreased because perennial grains have large root systems that hold soil in place (Glover et al. 2010). These roots can additionally lead to efficient retention of water and nutrients. Because perennial wheat and intermediate wheatgrass are able to retain water and nutrients much better than annual wheat, the amount of nitrates leached from farmland that grows perennial grains is expected to be greatly reduced (Glover et al. 2010). Less soil erosion and nitrate leaching lead to higher water quality in surrounding watersheds. It is also expected that perennial grains retain soil carbon better than annual wheat because of their large root systems. So, carbon sequestration and global climate change mitigation are other environmental benefits that could be associated with the growth of perennial wheat and intermediate wheatgrass (Glover et al. 2010).

Even though perennial grains are expected to offer environmental benefits, both crops would still be grown largely to provide grain (Glover et al. 2010). Perennial wheat and intermediate wheatgrass can also grow in areas with damaged or less-fertile soil. The very first researchers to develop perennial wheat aimed to create a crop that could yield grain on less-fertile land that could not be used to grow annual wheat (Armstrong 1945). Perennial grains also offer a byproduct in the form of forage. Both crops could be grazed by livestock in the late summer after the grain is harvested or in the early spring before the grain has developed, while still producing a grain yield (Bell et al. 2008). However, empirical research measuring the impact of grazing on the perenniality of perennial grain lines has just begun[1]. So, the ability to be grown on less fertile land, the production of wheat grain and forage, the generation of environmental benefits and decreased input requirements are the main motives for the development of perennial grains.

History of Perennial Grain Development

Perennial grains have been in development for almost a century, but not much funding was allocated to the studies that occurred in the 1900's. Their cultivation started in Russia in the 1920's. N.V. Tzitzin was a Russian researcher who crossed a species of Triticum with a species of Agropyron to form the first-ever perennial wheat lines (Armstrong 1945). The goal behind the Russian study was to increase wheat production in northern Russia, where the soil could not be used to grow annual wheat (Armstrong 1945).

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[1] S. Tinsley in the Crop and Soil Science Department at Michigan State University is currently performing trials that measure the impact of cutting on perenniality and biomass yield at the Kellogg Biological Station.

These studies continued in Russia for many years but eventually stopped in the 1950's because project expectations were never reached (Wagoner 1990). A few years after the first Russian studies began, interest in perennial wheat and intermediate wheatgrass came to the United States. Between 1923 and 1935 W.J. Sando, working for the United States Department of Agriculture, bred many lines of perennial wheat and advanced the development of intermediate wheatgrass (Vinall and Hein 1937). Sando's lines were then used in many different studies during the 1900's.

In 1935, J.M. Armstrong began the development of perennial wheat and intermediate wheatgrass in Canada. Working for the Canadian Department of Agriculture, Armstrong bred his own lines of perennial wheat with the goal of alleviating soil erosion in Canadian farm areas that were prone to drought (Armstrong 1945). Armstrong's research with utilizing perennial wheat to decrease soil erosion was the first incidence where perennial wheat was cultivated to provide an environmental benefit. After Armstrong's research, environmental benefits and ecosystem services became some of the main motivators behind other institutions' perennial grain development.

In 1938, Suneson and Pope at the University of California at Davis began to breed perennial grains specifically for the perennial trait. Perhaps because of this, the seven years of experiments that Suneson and Pope performed together created lines with good regrowth but very little grain yield (Suneson and Pope 1946). Regrowth and yield seem to be tradeoffs; the more that researchers focused on perenniality, the lower the grain yields seemed to be, and vice versa. By 1946, both researchers believed that much more work needed to be done to increase grain yields before perennial wheat could be commercially viable, so Suneson continued to study perennial grains over the next 25 years and made considerable advances in the perenniality of the lines (Suneson and Pope 1946 and Suneson et al. 1963). J. Schulz-Schaeffer at Montana State University began growing perennial wheat in 1970, and actually used some of the lines that Sando originally bred (Schulz-Schaeffer 1970). Along with S. E. Haller in the 1980's, Schulz-Schaeffer continued to grow perennial wheat specifically with the goal of decreasing soil erosion and reducing agricultural production costs (Schulz-Schaeffer and Haller 1987). More research institutions began developing perennial grains after the 1980's, as described below.

Recent and Current Research

P. Wagoner at the Rodale Research Center began developing perennial wheat in 1987 from seeds donated by Schulz-Schaeffer and Haller. Even though regrowth for these trials was very low, the experiments continued for many years (Wagoner 1990). In 1991, scientists at Washington State University started to research and cultivate perennial wheat lines on a small scale. Even though WSU started by growing small amounts of perennial wheat in greenhouses, they moved up to field trials in 1998 and quickly grew to being the largest research program on perennial wheat in the United States, having bred over two thousand lines by 2001 (Scheinost et al. 2001). WSU's development has mainly focused on establishing the perennial traits and enhancing the environmental benefits provided by perennial wheat, specifically soil erosion abatement and carbon sequestration (Scheinost et al. 2001).

Since 2000, researchers at the Land Institute (TLI) in Kansas have also been cultivating perennial grain lines. Although TLI mainly focuses on developing different lines of intermediate wheatgrass, they do have some trials that include perennial wheat. From 2000 to 2006, the first six years of TLI's perennial grain experiments, no perennial wheat lines showed signs of regrowth after harvest (Cox et al. 2006). However, TLI continues to develop perennial grains in the hope of finding the perennial trait, and has now become the largest developer of perennial wheat and intermediate wheatgrass in the United States.

Michigan State University acquired a grant to cultivate perennial grains in 2009. Since then, perennial wheat and intermediate wheatgrass lines have been grown in Mason, Michigan, and at the Kellogg Biological Station (KBS) near Battle Creek, Michigan. Researchers at KBS are cultivating perennial grain plants from seeds provided by WSU's 2009 and 2005 lines. At MSU, research is being conducted to study the possible environmental benefits that perennial grains may provide, whether or not they could be dual-use forage and grain crops and how profitable perennial grains are compared to annual wheat.

While studies are being conducted in Michigan and various other states in the U.S., other countries are also carrying out perennial grain experiments. From 2007 to 2010, perennial wheat and intermediate wheatgrass trials were conducted at the E. H. Graham Centre for Agricultural Innovation in New South Wales, Australia. The perennial wheat yield and management data that is included in this case study comes from Richard Hayes at this center (2012). A number of the perennial grain lines grown by researchers at the E. H. Graham Centre were able to grow for more than a year, meaning that some of the lines were actually perennial (Hayes et al. 2012). Additionally, researchers in China at the Yunnan Academy of Agricultural Sciences have also recently begun to develop new lines of perennial grains (Andrews 2010). So, there are many different research institutions in countries across the globe that have researched or are currently researching perennial wheat and intermediate wheatgrass. Even though perennial grains have been researched for almost a century, much more funding was put into the development of high-yielding wheat varieties during the Green Revolution than into the development of perennial wheat and intermediate wheatgrass in the years since the 1920's.

4.2 Budget Analyses

The profitability of an agricultural technology impacts whether or not the technology will be adopted. If the profit of an EB technology is lower than the net return of a conventional technology, the EB technology will not be adopted. Because of this, the profitability of perennial wheat and intermediate wheatgrass needs to be evaluated. This section looks at a number of different measures that describe the profits of the perennial wheat and intermediate wheatgrass lines from three Australian wheat trials, and applies the conceptual model to the data from those trials. The gross margins, which consist of the revenues of each line minus the annual variable costs of production (AVCP), explain if the revenues were greater than the AVCP for each line, and the net present values describe the profits of each wheat line over a number of years, given a specific discount rate.

The annualized net returns, which were the average annual returns provided by each wheat line over the lifetime of the line, were also found for each line of annual wheat, perennial wheat and intermediate wheatgrass given a specific discount rate. The profits of the perennial wheat and intermediate wheatgrass lines were then compared to the annual net return of the annual wheat line to evaluate if perennial wheat and intermediate wheatgrass were as profitable as annual wheat. The comparative breakeven budgets then calculated the yield gains, prices, costs and subsidy payments that would be necessary for the perennial wheat and intermediate wheatgrass lines to become as profitable as annual wheat.

Budget Components

The yield and management data that were included in the budget analyses came from Richard Hayes et al. 2012 in New South Wales, Australia. The budget analyses used this data to evaluate the profitability of the perennial wheat and intermediate wheatgrass lines from three wheat trials. Two of the trials took place in Cowra while the other trial was in Woodstock, both of which are in New South Wales. The first trial began in early 2008 in Cowra, and lasted for four years. The second trial was also conducted in Cowra, but was not started until early 2009, and lasted for three years. The final trial began in early 2009 in Woodstock, and only lasted for two years. Each trial also had an investment year where the soil was prepared for planting, which was considered to be 'year zero'.

The first trial (Cowra 2008) measured the grain yields of nine lines of perennial wheat, two of intermediate wheatgrass and one of annual wheat. The second trial (Cowra 2009) included 28 perennial wheat lines and one intermediate wheatgrass line, while the third trial (Woodstock) contained 13 perennial wheat lines and one intermediate wheatgrass line. The three trials included some of the same perennial wheat and intermediate wheatgrass lines. Because of this, there were a total of 43 different perennial wheat lines, two different intermediate wheatgrass lines and one annual wheat line in the three trials, not including the repeated lines that were planted in more than one trial.

Costs of the Wheat Trials

Specific inputs were used in the cultivation of the wheat lines in each of the three trials. Each input had a corresponding cost, and aggregating the costs of all of the inputs formed the annual variable costs of producing the wheat lines. Because commercial seed prices were unavailable for these experimental breeding lines, seed cost was omitted from the budgets. All of the trials utilized a number of pesticides and fertilizers. The pesticides used in the two Cowra trials were: glyphosate, flutriafol, a mix of MCPA and diflufenican, epoxiconazole and paraquat. The Woodstock trial used all of the same pesticides except paraquat; a mix of pinoxaden and cloquintocet-mexyl was used instead of paraquat. All of the pesticides applied to the wheat lines in the trials were herbicides or fungicides. All three trials used diammonium phosphate and urea fertilizers (Hayes et al. 2012). The costs of these pesticides and fertilizers were found by multiplying the input price by the total quantity of each input that was used. The costs were then added each year within each perennial wheat trial to form the cash input costs. The prices of theses inputs came from Haskins et al., 2010, while the quantities of the inputs came from Hayes et al., 2012. The cash input costs for the wheat lines in the two Cowra trials and the Woodstock trial are given in 2010 Australian dollars per hectare in the tables below.

Table 4.2.1 PW and IWG Cash Input Costs from Both Cowra Trials (AUS $)

Cash Inputs	**Quantity**	**Unit**	**Price ($/unit)**	**Yr 0**	**Yr 1**	**Yr 2/3/4**
Glyphosate	1	l/ha	4.5	4.5	0	0
Flutriafol	0.4	ml/ha	22.22	8.8	0	0
MCPA+Diflu.	250	g/ha	0.02	0	4.63	4.63
Epoxiconazole	1	g/ha	46.10	0	46.10	46.10
Paraquat	250	g/ha	0.008	0	2.1	2.10
DAP #1	100	kg/ha	0.82	82.00	0	0
DAP #2	20	kg/ha	0.82	0	16.40	16.40
Urea #1	26	kg/ha	0.7	18.20	0	0
Urea #2	30	kg/ha	0.7	0	21.00	21.00
Cash Inputs Total				113.60	90.23	90.23

Sources: input quantities from Hayes et al., 2012, input prices from Haskins et al., 2010.
Average currency exchange rate in 2010: 1 U.S. dollar to 1.15 Australian dollars.

Table 4.2.2 PW and IWG Cash Input Costs from the Woodstock Trial (AUS $)

Cash Inputs	**Quantity**	**Unit**	**Price**	**Yr 0**	**Yr 1**	**Yr 2**
Glyphosate	1	l/ha	4.5	4.5	0	0
Flutriafol	0.4	ml/ha	22.22	8.8	0	0
MCPA+Diflu.	250	g/ha	0.019	0	4.63	4.63
Epoxiconazole	1	g/ha	46.10	0	46.10	46.10
Pinox.+CM	250	ml/ha	0.15	0	37.50	37.50
DAP #1	100	kg/ha	0.82	82.00	0	0
DAP #2	20	kg/ha	0.82	0	16.40	16.40
Urea #1	26	kg/ha	0.7	18.20	0	0
Urea #2	30	kg/ha	0.7	0	21.00	21.00
Cash Inputs Total				113.58	125.63	79.53

Sources: input quantities from Hayes et al., 2012, input prices from Haskins et al., 2010.

Table 4.2.3 Annual Wheat Cash Input Costs from Cowra 2008 Trial (AUS $)

Cash Inputs	**Quantity**	**Unit**	**Price ($/unit)**	**Yr 0**	**Yr 1**
Glyphosate	1	l/ha	4.5	4.5	4.5
Flutriafol	0.4	ml/ha	22.22	8.8	8.8
MCPA+Diflu.	250	g/ha	0.02	0	4.63
Epoxiconazole	1	g/ha	46.10	0	46.10
Paraquat	250	g/ha	0.008	0	2.1
DAP #1	100	kg/ha	0.82	82.00	82.00
DAP #2	20	kg/ha	0.82	0	16.40
Urea #1	26	kg/ha	0.7	18.20	18.20
Urea #2	30	kg/ha	0.7	0	21.00
Cash Inputs Total				113.58	203.80

Sources: input quantities from Hayes et al., 2012, input prices from Haskins et al., 2010.

After calculating the cash input costs, the costs of custom production operations were found. These costs included all of the custom operations that were necessary to prepare the soil and plant, grow and harvest the perennial wheat, annual wheat and intermediate wheatgrass lines. The cost of utilizing a pesticide boomsprayer, fertilizer spreader and scarifier were some of the custom operational costs that were included (Hayes et al. 2012). All of the costs of custom production operations are included in the tables below. The custom rates (prices) were multiplied by the quantity of the operations that were used. The custom rate price information came from NSW Government, 2011, while the quantities came from Hayes et al., 2012. These costs were added on an annual basis in each individual wheat trial to form the total annual costs of custom production operations.

Table 4.2.4 PW and IWG Costs of Custom Operations from Both Cowra Trials (AUS $)

Custom Costs	**Quantity**	**Unit**	**Price ($/unit)**	**Yr 0**	**Yr 1**	**Yr 2/3/4**
Scarifier	1	ha	12.68	12.68	0	0
Boomsprayer #1	1	ha	12.00	12.00	0	0
Boomsprayer #2	1	ha	12.00	12.00	0	0
Fertilizer spreader #1	1	ha	3.51	3.51	0	0
Fertilizer spreader #2	1	ha	3.51	3.51	0	0
Hand sowing	1	ha	40.00	0	40.00	0
Boomsprayer #3	1	ha	12.00	0	12.00	12.00
Boomsprayer #4	1	ha	12.00	0	12.00	12.00
Contract harvest	1	ha	40.59	0	40.59	40.59
Boomsprayer #5	1	ha	12.00	0	12.00	12.00
Fertilizer spreader #3	1	ha	3.51	0	3.51	3.51
Fertilizer spreader #4	1	ha	3.51	0	3.51	3.51
Custom Costs Total				43.7	123.60	83.61

Sources: input quantities from Hayes et al., 2012, prices from NSW Government, 2011.

Table 4.2.5 PW and IWG Costs of Custom Operations from Woodstock Trial (AUS $)

Custom Costs	**Quantity**	**Unit**	**Price**	**Yr 0**	**Yr 1**	**Yr 2**
Scarifier	1	ha	12.68	12.68	0	0
Boomsprayer #1	1	ha	12.00	12.00	0	0
Boomsprayer #2	1	ha	12.00	12.00	0	0
Fertilizer spreader #1	1	ha	3.51	3.51	0	0
Fertilizer spreader #2	1	ha	3.51	3.51	0	0
Hand sowing	1	ha	40.00	0	40.00	0
Boomsprayer #3	1	ha	12.00	0	12.00	12.00
Boomsprayer #4	1	ha	12.00	0	12.00	12.00
Boomsprayer #5	1	ha	12.00	0	12.00	12.00
Contract harvest	1	ha	40.59	0	40.59	40.59
Fertilizer spreader #3	1	ha	3.51	0	3.51	3.51
Fertilizer spreader #4	1	ha	3.51	0	3.51	3.51
Custom Costs Total				43.7	123.61	83.61

Sources: input quantities from Hayes et al., 2012, prices from NSW Government, 2011.

Table 4.2.6 Annual Wheat Costs of Custom Operations from Cowra 2008 (AUS $)

Custom Costs	**Quantity**	**Unit**	**Price**	**Yr 0**	**Yr 1**
Scarifier	1	ha	12.68	12.68	12.68
Boomsprayer #1	1	ha	12.00	12.00	12.00
Boomsprayer #2	1	ha	12.00	12.00	12.00
Fertilizer spreader #1	1	ha	3.51	3.51	3.51
Fertilizer spreader #2	1	ha	3.51	3.51	3.51
Hand sowing	1	ha	40.00	0	40.00
Boomsprayer #3	1	ha	12.00	0	12.00
Boomsprayer #4	1	ha	12.00	0	12.00
Contract harvest	1	ha	40.59	0	40.59
Boomsprayer #5	1	ha	12.00	0	12.00
Fertilizer spreader #3	1	ha	3.51	0	3.51
Fertilizer spreader #4	1	ha	3.51	0	3.51
Custom Costs Total				43.7	167.31

Sources: input quantities from Hayes et al., 2012, prices from NSW Government, 2011.

Once the annual costs of custom production operations were found, they were added to the cash input costs to generate the annual variable costs of production (AVCP) for each trial. The cost of the seeds, farmland and post-harvest costs such as trucking and marketing were not included in the AVCP, so AVCP refers to all of the costs besides these. In each trial there was a 'year zero' in addition to the years during which the wheat lines grew. Year zero's costs consisted of soil preparation only, and no yield was produced in year zero since the wheat was not planted until year one. So, the AVCP of each wheat trial were found for year zero, and years one through four for the Cowra 2008 trial, years one through three for the Cowra 2009 trial and years one and two for the Woodstock trial. The AVCP for each trial were generated in 2010 Australian dollars per hectare, and are provided in the appendix at the end of this chapter. Table A.4.1 contains the AVCP of the two Cowra perennial wheat and intermediate wheatgrass trials, table A.4.2 includes the AVCP of the growth of the annual wheat line in the Cowra 2008 trial and table A.4.3 includes the AVCP of the Woodstock trial.

Revenues of the Wheat Trials

After finding the AVCP for each of the three trials, the total revenues of the annual wheat, perennial wheat and intermediate wheatgrass lines were found. Hayes et al. provided perennial wheat and intermediate wheatgrass grain yield data in grams per row for the Cowra trials and grams per plot for the Woodstock trials (2012). The rows in the Cowra trials were fairly small; they were one meter by 27 centimeters in the 2008 trial and one and a half meters by 52 centimeters in the 2009 trial. The Woodstock plots were larger at seven and a half meters long by two meters wide. The yields from each wheat line were aggregated to the hectare level since the costs were generated on a hectare level. The grain yield of each wheat line was first found in kilograms of grain per hectare, and was then converted to tons of grain per hectare. Once the grain yields for each of the wheat lines were found, the price of the grain could also be found. Together, these two components formed the total revenues for each wheat line.

The price of the perennial wheat and intermediate wheatgrass grain was assumed to be equivalent to the 2010 price of Australian feed wheat grain (R. Hayes, personal communication by e-mail, 10/25/2011). Historic prices for Australian feed wheat grain over the last 30 years were found and adjusted for inflation by the Australian consumer price index (Australian Bureau of Statistics 2011, a). A linear trend regression was estimated to find the relationship between the year and the adjusted price of the feed wheat grain. (A quadratic regression was also estimated, but an F test showed that the linear regression was equally informative.) So, the linear regression was used to predict the 2010 adjusted feed wheat grain price in Australian dollars per ton, which served as the baseline grain price for the perennial wheat and intermediate wheatgrass lines in the three trials. The 2010 adjusted price of the perennial wheat and intermediate wheatgrass grain was 297 Australian dollars per ton.

The same procedure was used to estimate the adjusted 2010 Australian price of food wheat grain, which was used as the price for the annual wheat grain. Thirty years of historic Australian food wheat grain prices were found and adjusted by the consumer price index, and a linear regression was used to find the adjusted 2010 price of annual wheat grain in Australian dollars per ton (ABS 2011a). Given this process, the estimated 2010 adjusted price of annual wheat grain was 372 Australian dollars per ton.

The price of the perennial wheat and intermediate wheatgrass as feed grain was considerably lower than the annual wheat price because feed grains traditionally have lower prices than food grains. To find the per hectare revenues of the perennial wheat and intermediate wheatgrass lines, the annual grain yield for each line in tons per hectare was multiplied by $297. To find the annual per hectare revenue of the annual wheat line, the grain yield in tons per hectare was multiplied by $372. So, annual revenues were found for each wheat line in the three wheat trials. Tables A.4.4, A.4.5 and A.4.6 in the appendix at the end of the chapter include the revenues from each different wheat line in each of the three trails. Table A.4.4 shows the revenues of the Cowra 2008 trial, table A.4.5 includes the revenues of the Cowra 2009 trial and table A.4.6 contains the revenues of the Woodstock trial.

Profitability Measures

Gross Margins

In order to find the annual gross margins of each wheat line, the annual variable costs of production were subtracted from the annual revenues of each line. Gross margins over variable production costs were generated for years one through four for the Cowra 2008 trial, years one through three for the Cowra 2009 trial and years one and two for the Woodstock trial. Since no grain was produced in the investment year, year zero had negative gross margins for each wheat line in all of the trials. The gross margins were calculated in 2010 Australian dollars per hectare, since the revenues and costs were found on a hectare basis. Since the AVCP did not include the costs of seed, farmland or any post-harvest costs, the gross margins also did not take those costs into account.

The results of the analysis showed that the year one gross margin of the annual wheat line was positive while many of the gross margins of the perennial wheat and intermediate wheatgrass lines were negative. When the gross margins were negative, the cost of growing the wheat lines was greater than the revenues produced by the lines. Many of the intermediate wheatgrass and perennial wheat lines had positive gross margins in year one, before the wheat lines showed their perennial traits. In the Cowra 2008 trial, five perennial wheat lines had positive gross margins in year one. In the Cowra 2009 trial, six perennial wheat lines had positive gross margins in year one, while only one line had a positive gross margin in year one in the Woodstock trial. The number of lines that had positive gross margins in the years after year one decreased in the Cowra 2008 trial and in the Woodstock trial. In the Cowra 2008 trial, there were only two lines that had positive gross margins in year two, and in the Woodstock trial, none of the lines had positive gross margins in year two. However, in the Cowra 2009 trial, 12 perennial wheat lines had a positive gross margin in year two. But after year two in both of the Cowra trials, hardly any lines had positive gross margins.

Overall, none of the perennial wheat or intermediate wheatgrass lines had positive gross margins every year of their lifetime. Even the few promising perennial wheat lines in the Cowra 2009 trial that had positive gross margins in years one and two went on to have negative gross margins in year three. These results highlighted the fact that for most of the perennial wheat and intermediate wheatgrass lines, the annual revenues were smaller than the annual variable costs of production. The annual gross margins for each wheat line in all three of the trials are given in tables A.4.7, A.4.8 and A.4.9 in the appendix below.

Net Present Values

Net present values at two different discount rates were found for each wheat line in the three Australian wheat trials. These net present values showed whether or not the revenues of the wheat lines outweighed the AVCP over the lifetime of each line. The NPV's were found through aggregating and discounting the gross margins and year zero investment costs over the lifetime of each of the wheat lines. The equation used to calculate the net present values was:

$$NPV = \Sigma R_t/(1 + i)^t \qquad (2)$$

In equation 2, R_t is assumed to be the net cash flow, i is the discount rate and t is the year of the cash flow. The NPV's were thus found by discounting two, three or four years of cash flows (depending on the length of the trial), and then summing the discounted cash flows and year zero's investment costs. The two discount rates that were used to find the NPV's were eight percent and 12%. These values were, respectively, the average and the maximum interest rates on three-year fixed term small business loans in Australia over the past 20 years (Reserve Bank of Australia 2011). Using these two discount rates, two net present values were found for each annual wheat, perennial wheat and intermediate wheatgrass line to show if the lines were profitable over time.

The perenniality of the perennial wheat and intermediate wheatgrass lines greatly impacted the net present values of the wheat lines. Theoretically, if the lines were to die early and thus not be very perennial, their net present values would be lower. Also, perenniality is fundamental to the average grain yield produced by each wheat line; well-established perennial wheat and intermediate wheatgrass lines should produce larger grain yields if they live for more years. Since perenniality could greatly impact the average yields and net present values of the perennial wheat and intermediate wheatgrass lines, perenniality could largely influence the profitability of the wheat lines. The impact of perenniality on the profitability of the perennial wheat and intermediate wheatgrass lines from the three Australian wheat trials is discussed in section 5.3.

In the wheat trials, most of the perennial wheat and intermediate wheatgrass lines had net present values that were below zero. In addition to the annual wheat line, only four perennial wheat lines and one intermediate wheatgrass line had positive net present values. Additionally, the NPV from the annual wheat line was greater than the NPV's from any of the perennial wheat or intermediate wheatgrass lines. So given a four-year time period, the annual wheat line had the highest net present value out of all of the wheat lines in the Australian trials, and was thus more profitable than any of the perennial wheat or intermediate wheatgrass lines.

Even though none of the perennial wheat or intermediate wheatgrass lines had a net present value as high as that of annual wheat, five perennial wheat and intermediate wheatgrass lines still had positive NPV's. The annual wheat line came from the Cowra 2008 trial and had an NPV of $884 at an eight percent discount rate and $846 at a 12% discount rate over four years. Dundas, the intermediate wheatgrass line with a positive NPV, also came from the Cowra 2008 trial and had a net present value of $132 with an eight percent discount rate and $61 with a 12% rate. However, Dundas was also grown in the Cowra 2009 trial and in the Woodstock trial, and did not have a positive NPV in either of those trials.

The four perennial wheat lines that had positive net present values all came from the Cowra 2009 trial. The perennial wheat line with the highest NPV was C64a, which had an NPV of $534 at the eight percent discount rate and $515 at the 12% rate. The other three lines had smaller NPV's, but they were still positive. C39b had an NPV of $127 at eight percent and $123 at 12%, C47b had an NPV of $33 at eight percent and $27 at 12%, and O42 had an NPV of $34 at eight percent and $38 at 12%. O42 was also grown in the Cowra 2008 trial and in the Woodstock trial, but had a negative NPV in both of those trials. The NPV's at eight percent and 12% for every wheat line in each trial are given in tables A.4.10, A.4.11 and A.4.12 in the appendix at the end of the chapter. Although Dundas, C64a, C39b, C47b and O42 showed promise, the annual wheat line had a higher NPV than any of the perennial wheat or intermediate wheatgrass lines in all of the trials.

Application of the Conceptual Model

The conceptual model established earlier in this paper was applied to the data provided by the three Australian wheat trials. Annualized net returns (not including the cost of land, seed or post-harvest costs) were found for the one line of annual wheat and for each line of perennial wheat and intermediate wheatgrass. The net returns of the perennial wheat and intermediate wheatgrass lines were then compared to the net return from the annual wheat line to assess the profitability of the perennial wheat and intermediate wheatgrass lines. Comparative breakeven prices, yields, subsidy payments and costs that would allow the perennial wheat and intermediate wheatgrass lines to become as profitable as the annual wheat line were also found.

Annualized Net Returns

The annualized net returns of each wheat line were found by annualizing the net present values of the lines over a three-year lifespan using an eight percent discount rate. The equation used to calculate the annualized net returns is the same equation that is used to find annual annuity payments:

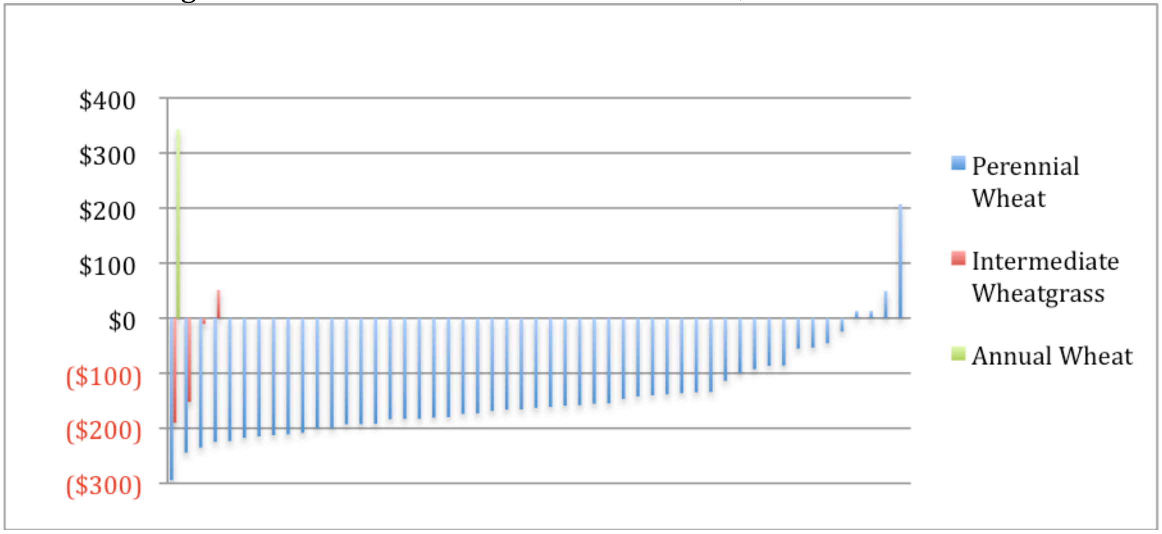
$$ANR = NPV/[(1-(1/(1+i)^{t}))/i] \qquad (3)$$

In equation 3, NPV is the net present value of the wheat line, i is the discount rate and t is the number of years that the NPV is annualized over (Cedar Spring Software Inc., 2002). In order to compare the net returns of each wheat line between the three trials, the net returns had to be generated using the same number of base years. So, the annualized net returns for every wheat line were found using a three-year base lifespan, even the one line from the Cowra 2008 trial that lasted for four years and all of the lines from the Woodstock trial that lasted for two years. Since the Woodstock trial only lasted for two years, the NPV that was used to form the annualized net returns for that trial consisted of the grain yields from two years only. By annualizing the net present value of each wheat line over three years given an eight percent discount rate, the annualized net returns for the annual wheat, perennial wheat and intermediate wheatgrass lines were found.

None of the perennial wheat or intermediate wheatgrass lines had annualized net returns that were greater than or equal to the net return of the annual wheat line. Given the three-year base and the eight percent discount rate, the annualized net return of the annual wheat line was $343 per hectare. The annualized net returns of all five perennial wheat and intermediate wheatgrass lines with positive NPV's were significantly smaller than that. Dundas had an annualized net return of $51 per hectare, C39b had a net return of $49, C47b and O42 both had net returns of $13 and C64a had a net return of $207. The net return of C64a was closest to that of the annual wheat line, but the net returns were still different by almost $150 per hectare.

Since the net returns of the five most promising perennial wheat and intermediate wheatgrass lines were smaller than the net return of the annual wheat line, and because the net return of every other perennial wheat and intermediate wheatgrass line was negative, none of the perennial wheat or intermediate wheatgrass lines were as profitable as the annual wheat line. The net returns of each wheat line are given in tables A.4.13, A.4.14 and A.4.15 in the appendix. Some of the negative net returns were close to zero, such as negative ten dollars for Dundas in the Cowra 2009 trial. However, other negative net returns were very far from zero, like (-$294) for C58a in the Cowra 2008 trial. A graph of the net returns of all of the annual wheat, perennial wheat and intermediate wheatgrass lines is given below. In order for any of the perennial wheat or intermediate wheatgrass lines to become as profitable as annual wheat, changes must be made to their prices, yields, costs or subsidy payments. These changes are explored in the rest of this section.

Figure 4.2.1 Annualized Net Returns of AW, PW and IWG Lines



*For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

Comparative Breakeven Prices and Yields

An increase in the price or yield of the perennial wheat or intermediate wheatgrass lines would allow the profits of the wheat lines to equal the net return of the annual wheat line. At the original price of $297 per ton and the original grain yields, none of the perennial wheat or intermediate wheatgrass lines had an annualized net return of $343, which was the annualized net return of the annual wheat line given an eight percent discount rate. So, the comparative breakeven prices that would allow the profits of the perennial wheat and intermediate wheatgrass lines to be equal to the net return of annual wheat would be greater than $297, and all of the comparative breakeven yields would be greater than the original grain yields.

The comparative breakeven prices and yields of each line of perennial wheat and intermediate wheatgrass were the prices and yields that allowed the profit of the wheat lines to be equal to the net return of the annual wheat line. The comparative breakeven prices are represented by p_{CB} in the following equation:

$$p_{CB} = (NR_0 + c_N)/y_N \qquad (4)$$

It is assumed that in equation 4, NR_0 is the net return of the annual wheat line, which is an annuity value for one year of survival. Also, c_N is the average annual variable costs of production of the perennial wheat and intermediate wheat grass lines, and y_N is the average annual grain yield of the perennial wheat and intermediate wheatgrass lines over the perennial period. Consequently, the comparative breakeven prices of the perennial wheat and intermediate wheatgrass lines were equal to the annual net returns of the annual wheat line plus the annual variable costs of production of the perennial wheat and intermediate wheatgrass lines, divided by the average annual grain yield of the perennial wheat and intermediate wheatgrass lines.

The equation and assumptions used to find the comparative breakeven yields for the perennial wheat and intermediate wheatgrass lines were similar. The average annual comparative breakeven grain yields are given as y_{CB} in the equation below:

$$y_{CB} = (NR_0 + c_N)/p_N \qquad (5)$$

In equation 5, NR_0 is assumed to be the annual net return of the annual wheat line, c_N is the average annual variable costs of production of the perennial wheat and intermediate wheatgrass lines and p_N is the price of the perennial wheat and intermediate wheatgrass grain ($297/ton, as described above). So, the average annual comparative breakeven grain yields of the perennial wheat and intermediate wheatgrass lines were found by adding the average perennial wheat and intermediate wheatgrass AVCP to the annual net return of the annual wheat line and dividing by the price of the perennial wheat and intermediate wheatgrass grain.

The four perennial wheat lines and one intermediate wheatgrass line that had positive net returns had comparative breakeven prices and yields that were quite a bit greater than their original prices and yields. The prices that would make the profits of the perennial wheat and intermediate wheatgrass lines equal the net return of the annual wheat line were: $544 per ton for Dundas, $589 for C39b, $670 for C47b and O42 and $385 for C64a. All of these prices were significantly higher than $297, the original price of the perennial wheat and intermediate wheatgrass grain. The comparative breakeven prices of the other perennial wheat and intermediate wheatgrass lines were all greater than $670.

Improvements in the quality of the perennial wheat or intermediate wheatgrass grain through breeding or genetics could generate an increase in the price of the grain. However, perennial wheat and intermediate wheatgrass grain would most likely not receive a price much higher than the price of annual wheat, which was $372 in this study. Line C64a had the closest comparative breakeven price to that of annual wheat, making it the most promising line. The comparative breakeven prices of the other perennial wheat and intermediate wheatgrass lines were all much larger than the price of annual wheat, and would thus be less feasible to attain through changes in grain quality.

An increase in grain yield through wheat breeding or genetics is another option for increasing the profitability of the perennial wheat and intermediate wheatgrass lines. The yield gains of each of the five perennial wheat and intermediate wheatgrass lines would need to be: 83% for Dundas, 98% for C39b, 126% for C47b and O42 and 30% for C64a. These results show that line C64a would again be the most promising line because it would require the smallest increase in grain yield. All of the other perennial wheat and intermediate wheatgrass lines that had negative annualized net returns would require yield gains greater than 126% to breakeven with annual wheat. So, increases in the grain price or yield of all of the lines of perennial wheat and intermediate wheatgrass could make their profits equal the net return of annual wheat. The comparative breakeven prices and yield gains of all of the perennial wheat and intermediate wheatgrass lines from the three Australian wheat trials are given in tables A.4.16, A.4.17 and A.4.18 in the appendix below.

Comparative Breakeven Subsidy Payments

Since none of the perennial wheat or intermediate wheatgrass lines had profits that were as high as the net return of annual wheat, subsidies could theoretically be paid to growers of perennial wheat or intermediate wheatgrass to make the profit of the wheat lines equal the net return of annual wheat. As noted above, perennial wheat and intermediate wheatgrass provide a number of environmental benefits including carbon sequestration, reduced soil erosion and decreased nitrate leaching. Subsidies could be paid to growers of perennial wheat and intermediate wheatgrass to compensate them for the production of these off-farm environmental benefits. These external environmental benefits would be internalized through the payment of subsidies to growers. The annual comparative breakeven subsidy payment is represented by σ_{CB} in the equation below:

$$\sigma_{CB} = NR_0 + c_N - (p_N \cdot y_N) \qquad (6)$$

In equation 6, NR_0 is the annual net return of annual wheat, c_N is the average AVCP of the perennial wheat and intermediate wheatgrass lines, p_N is the original price of the perennial wheat and intermediate wheatgrass grain ($297/ton) and y_N is the average annual grain yield of the perennial wheat and intermediate wheatgrass lines. Since there was a wide range of net returns from all of the perennial wheat and intermediate wheatgrass lines, there was also a wide range of annual comparative breakeven subsidy payments. The annual per hectare subsidy payments that would allow the net returns of each line of perennial wheat and intermediate wheatgrass to equal the annual net return of the annual wheat line are given in tables A.4.19, A.4.20 and A.4.21 in the appendix at the end of the chapter.

The five lines of perennial wheat and intermediate wheatgrass that had positive NPV's also required the lowest subsidy payments in order to become as profitable as annual wheat. Out of the three trials, perennial wheat line C64a would require the smallest subsidy payment of $136 per hectare in order to become as profitable as the annual wheat line. The other four lines would need larger subsidy payments for their profits to equal the net return of annual wheat. Dundas would need an annual subsidy of $292 per hectare, C39b would need a subsidy of $294, and C47b and O42 would both need a subsidy of $330. If a grower were to receive these subsidy payments each year, the profit of each wheat line would equal the net return of annual wheat, and the five lines would be as profitable as the annual wheat line. Since every other line of perennial wheat and intermediate wheatgrass had negative net returns, they would require even larger subsidy payments to become as profitable as annual wheat.

The comparative breakeven subsidy payments that would be required to make the perennial wheat and intermediate wheatgrass lines profitable were very large, as shown above. These subsidy values might not be realistic depending on whether or not the value of the perennial grains' external benefits needed to justify the subsidies would be as high as the comparative breakeven subsidies. So although the comparative breakeven subsidies could make the perennial wheat and intermediate wheatgrass lines as profitable as annual wheat, the subsidy amounts may be too large to be economically feasible, assuming that the subsidy payments would not be accompanied by any genetic improvements that would increase the prices or yields of the grain.

Comparative Breakeven Costs

While a comparative breakeven subsidy would be a payment that could be made to a grower that would allow perennial wheat to become as profitable as annual wheat, a comparative breakeven cost would be the annual average cost that the grower would have to pay that would still allow perennial wheat or intermediate wheatgrass to become as profitable as annual wheat. The comparative breakeven annual variable costs of production were represented by c_{CB} in the following equation:

$$c_{CB} = (p_N \cdot y_N) - NR_0 \qquad (7)$$

It is assumed that p_N is the original price of the perennial wheat and intermediate wheatgrass grain ($297/ton), y_N is the average annual grain yield of the perennial wheat and intermediate wheatgrass lines and NR_0 is the annual net return of the annual wheat line. Therefore, the comparative breakeven AVCP were found through subtracting annual wheat's net return from the annual total revenues of the perennial wheat and intermediate wheatgrass lines.

The results showed that the annual variable costs of production of almost every perennial wheat and intermediate wheatgrass line would have to be negative for the profits of the lines to equal annual wheat's net return. Only line C64a could have a positive AVCP and still break even with annual wheat, although the AVCP would have to be $51 per hectare, which is too small to be economically feasible. A negative cost is similar to a subsidy payment, but they are not the same. A comparative breakeven subsidy would be a payment to the grower that would allow the grower to breakeven, while a negative cost would call for the AVCP to decrease to zero and would then require an additional payment to the grower for the grower to break even. So, no positive level of comparative breakeven AVCP would equalize the net returns of almost all of the lines from the three Australian wheat trials. Since a decrease in the annual costs of the perennial wheat and intermediate wheatgrass lines alone would not allow the wheat lines to become as profitable as annual wheat, the negative comparative breakeven annual variable costs of production are economically infeasible and are not provided here.

4.3 Conclusion

This chapter provided a literature review detailing the background of perennial wheat and intermediate wheatgrass, and a number of measures that estimated the profitability of the perennial wheat, intermediate wheatgrass and annual wheat lines. The comparative breakeven analyses were viable because they showed how the components of the perennial wheat and intermediate wheatgrass lines could be changed so that their profits would become equal to the net return of the annual wheat line. However, these comparative breakeven analyses also contained some limitations. Specifically, the analyses did not include realistic subsidy values that were based on the external environmental benefits provided by perennial wheat and intermediate wheatgrass. In the next chapter, a benefit transfer study is performed to place values on intermediate wheatgrass and perennial wheat's reduction in soil erosion, which generates accurate subsidy estimates that reflect monetary values of the benefits of soil erosion reduction. These subsidy values are then added to the gross margins of the perennial wheat and intermediate wheatgrass lines in order to find comparative breakeven prices, yields and costs that internalize the external environmental benefits.

APPENDIX

CHAPTER FOUR APPENDIX

Table A.4.1 Cowra 2008 and 2009 Trials, PW and IWG Costs (AUS $)

Cash Inputs	**Quantity**	**Unit**	**Price**[2]	**Yr 0**	**Yr 1**	**Yr 2/3/4**
Glyphosate	1	l/ha	4.5	4.5	0	0
Flutriafol	0.4	ml/ha	22.22	8.8	0	0
MCPA+Diflu.	250	g/ha	0.02	0	4.63	4.63
Epoxiconazole	1	g/ha	46.10	0	46.10	46.10
Paraquat	250	g/ha	0.008	0	2.10	2.10
DAP #1	100	kg/ha	0.82	82.0	0	0
DAP #2	20	kg/ha	0.82	0	16.40	16.40
Urea #1	26	kg/ha	0.7	18.20	0	0
Urea #2	30	kg/ha	0.7	0	21.00	21.00
Cash Inputs Total				113.60	90.23	90.23
Custom Costs						
Scarifier	1	ha	12.68	12.68	0	0
Boomsprayer #1	1	ha	12.00	12.00	0	0
Boomsprayer #2	1	ha	12.00	12.00	0	0
Fertilizer spreader #1	1	ha	3.51	3.51	0	0
Fertilizer spreader #2	1	ha	3.51	3.51	0	0
Hand sowing	1	ha	40.00	0	40.00	0
Boomsprayer #3	1	ha	12.00	0	12.00	12.00
Boomsprayer #4	1	ha	12.00	0	12.00	12.00
Contract harvest	1	ha	40.59	0	40.59	40.59
Boomsprayer #5	1	ha	12.00	0	12.00	12.00
Fertilizer spreader #3	1	ha	3.51	0	3.51	3.51
Fertilizer spreader #4	1	ha	3.51	0	3.51	3.51
Custom Costs Total				43.70	123.60	83.61
Annual Variable Costs of Production				157.30	213.80	173.80

Sources: input quantities from Hayes et al., 2012, input prices from Haskins et al., 2010 and NSW Government, 2011.

[2] All prices are given in 2010 Australian dollars. The average 2010 currency exchange rate was 1 U.S. dollar to 1.15 Australian dollars.

Table A.4.2 Cowra 2008 Trial, Annual Wheat Costs (AUS $)

Cash Inputs	Quantity	Unit	Price ($/unit)	Yr 0	Yr 1
Glyphosate	1	l/ha	4.5	4.5	4.5
Flutriafol	0.4	ml/ha	22.22	8.8	8.8
MCPA+Diflu.	250	g/ha	0.019	0	4.63
Epoxiconazole	1	g/ha	46.10	0	46.10
Paraquat	250	g/ha	0.008	0	2.10
DAP #1	100	kg/ha	0.82	82.00	82.00
DAP #2	20	kg/ha	0.82	0	16.40
Urea #1	26	kg/ha	0.7	18.20	18.20
Urea #2	30	kg/ha	0.7	0	21.00
Cash Inputs Total				113.60	203.80
Custom Costs					
Scarifier	1	ha	12.68	12.68	12.68
Boomsprayer #1	1	ha	12.00	12.00	12.00
Boomsprayer #2	1	ha	12.00	12.00	12.00
Fertilizer spreader #1	1	ha	3.51	3.51	3.51
Fertilizer spreader #2	1	ha	3.51	3.51	3.51
Hand sowing	1	ha	40.00	0	40.00
Boomsprayer #3	1	ha	12.00	0	12.00
Boomsprayer #4	1	ha	12.00	0	12.00
Contract harvest	1	ha	40.59	0	40.59
Boomsprayer #5	1	ha	12.00	0	12.00
Fertilizer spreader #3	1	ha	3.51	0	3.51
Fertilizer spreader #4	1	ha	3.51	0	3.51
Custom Costs Total				43.70	167.31
Annual Variable Costs of Production				157.30	371.12

Sources: input quantities from Hayes et al., 2012, input prices from Haskins et al., 2010 and NSW Government, 2011.

Table A.4.3 Woodstock Trial Costs (AUS $)

Cash Inputs	**Quantity**	**Unit**	**Price**	**Yr 0**	**Yr 1**	**Yr 2**
Glyphosate	1	l/ha	4.5	4.5	0	0
Flutriafol	0.4	ml/ha	22.22	8.8	0	0
MCPA+Diflu.	250	g/ha	0.02	0	4.63	4.63
Epoxiconazole	1	g/ha	46.10	0	46.20	46.10
Pinox.+CM	250	ml/ha	0.15	0	37.50	37.50
DAP #1	100	kg/ha	0.82	82.00	0	0
DAP #2	20	kg/ha	0.82	0	16.40	16.40
Urea #1	26	kg/ha	0.7	18.20	0	0
Urea #2	30	kg/ha	0.7	0	21.00	21.00
Cash Inputs Total				113.58	125.63	79.53
Custom Costs						
Scarifier	1	ha	12.68	12.68	0	0
Boomsprayer #1	1	ha	12.00	12.00	0	0
Boomsprayer #2	1	ha	12.00	12.00	0	0
Fertilizer spreader #1	1	ha	3.51	3.51	0	0
Fertilizer spreader #2	1	ha	3.51	3.51	0	0
Hand sowing	1	ha	40.00	0	40.00	0
Boomsprayer #3	1	ha	12.00	0	12.00	12.00
Boomsprayer #4	1	ha	12.00	0	12.00	12.00
Boomsprayer #5	1	ha	12.00	0	12.00	12.00
Contract harvest	1	ha	40.59	0	40.59	40.59
Fertilizer spreader #3	1	ha	3.51	0	3.51	3.51
Fertilizer spreader #4	1	ha	3.51	0	3.51	3.51
Custom Costs Total				43.70	123.61	83.61
Annual Variable Costs of Production				157.29	249.24	163.14

Sources: input quantities from Hayes et al., 2012, input prices from Haskins et al., 2010 and NSW Government, 2011.

Table A.4.4 Revenues of the Cowra 2008 Trial (AUS $/Hectare)

PW, AW, or IWG	**Line ID**	**Yr 1**	**Yr 2**	**Yr 3**	**Yr4**
AW	Wedgetail	1495	0	0	0
PW	O42	534	184	0	0
PW	Ot-38	169	71	0	0
PW	C35a	419	145	0	0
PW	C36a	466	262	64	0
PW	C36b	376	51	0	0
PW	C51b	404	54	3	0
PW	C57b	62	108	40	11
PW	C58a	7	5	0	0
PW	C86a	207	2	0	0
IWG	Th. Intermedium	2	20	329	0
IWG	Dundas	0	36	0	1185

Sources: grain yields from Hayes et al., 2012, prices from Australian Bureau of Statistics, 2011, a.

Table A.4.5 Revenues of the Cowra 2009 Trial

PW or IWG	**Line ID**	**Yr 1**	**Yr 2**	**Yr 3**
PW	C27a&b	193	0.11	0
PW	C231a	122	208	0
PW	C31b	75	68	0
PW	C33a	159	0.57	0
PW	C33b	113	129	0
PW	C34b	60	50	0
PW	C36a	183	209	0
PW	C36b	234	217	0
PW	C39b	567	286	0
PW	C40a	10	159	0
PW	C42b	139	56	0
PW	C44b	54	215	0
PW	C46a	362	197	0
PW	C47b	293	472	0
PW	C49b	31	114	0
PW	C51a	101	1	0
PW	C57b	15	27	0
PW	C58b	87	2	0
PW	C64a	994	298	0
PW	C79a	196	265	14
PW	C80a	91	70	0.94
PW	C80b	127	182	3
PW	C81b	130	79	8
PW	C88a	5	9	0
PW	C91b	101	14	0
PW	Ot-38	193	363	13
PW	O42	610	129	0
PW	TAF46	29	250	0
IWG	Dundas	36	0	733

Sources: grain yields from Hayes et al., 2012, grain prices from Australian Bureau of Statistics, 2011, a.

Table A.4.6 Revenues of the Woodstock Trial

PW or IWG	Line ID	Yr 1	Yr 2
PW	C35a	109	95
PW	C36a	29	35
PW	C36b	43	20
PW	C44a	327	4
PW	C51b	66	25
PW	C64a	136	2
PW	C68a	133	6
PW	C68b	118	3
PW	C69b	103	5
PW	C71b	122	68
PW	C86b	55	5
PW	O42	86	44
PW	Ot-38	42	63
PW	Zhong1	178	2
IWG	Dundas	7	152

Sources: grain yields from Hayes et al., 2012, grain prices from Australian Bureau of Statistics, 2011, a.

Table A.4.7 Gross Margins from the Cowra 2008 Trial (AUS $/Ha)

PW, AW, or IWG	Line ID	Yr 1	Yr 2	Yr 3	Yr 4
AW	Wedgetail	1124	0	0	0
PW	O42	320	11	-174	-174
PW	Ot-38	-45	-103	-174	-174
PW	C35a	205	-28	-174	-174
PW	C36a	252	88	-110	-174
PW	C36b	162	-123	-174	-174
PW	C51b	191	-120	-171	-174
PW	C57b	-151	-66	-133	-163
PW	C58a	-207	-169	-174	-174
PW	C86a	-7	-137	-174	-174
IWG	Th. Intermedium	-212	-154	155	-174
IWG	Dundas	-214	-137	-174	1011

Table A.4.8 Gross Margins from the Cowra 2009 Trial

PW or IWG	Line ID	Yr 1	Yr 2	Yr 3
PW	C27a&b	-21	-174	-174
PW	C31a	-92	34	-174
PW	C31b	-139	-106	-174
PW	C33a	-55	-173	-174
PW	C33b	-101	-45	-174
PW	C34b	-154	-124	-174
PW	C36a	-31	35	-174
PW	C36b	20	43	-174
PW	C39b	353	112	-174
PW	C40a	-204	-15	-174
PW	C42b	-75	-118	-174
PW	C44b	-160	41	-174
PW	C46a	149	23	-174
PW	C47b	79	299	-174
PW	C49b	-183	-60	-174
PW	C51a	-113	-172	-174
PW	C57b	-199	-147	-174
PW	C58b	-127	-172	-174
PW	C64a	780	124	-174
PW	C79a	-18	91	-160
PW	C80a	-122	-104	-173
PW	C80b	-87	8	-171
PW	C81b	-84	-95	-166
PW	C88a	-209	-165	-174
PW	C91b	-113	-160	-174
PW	Ot-38	-21	189	-161
PW	O42	396	-45	-174
PW	TAF46	-205	76	-174
IWG	Dundas	-178	-174	559

Table A.4.9 Gross Margins from the Woodstock Trial

PW or IWG	Line ID	Yr 1	Yr 2
PW	C35a	-140	-68
PW	C36a	-220	-129
PW	C36b	-206	-144
PW	C44a	78	-159
PW	C51b	-184	-139
PW	C64a	-114	-161
PW	C68a	-116	-157
PW	C68b	-131	-160
PW	C69b	-146	-159
PW	C71b	-127	-95
PW	C86b	-195	-158
PW	O42	-163	-119
PW	Ot-38	-207	-100
PW	Zhong1	-71	-161
IWG	Dundas	-243	-12

Table A.4.10 Net Present Values from the Cowra 2008 Trial (AUS $/Ha)

PW, AW, or IWG	Line ID	NPV at 8% Discount	NPV at 12% Discount
AW	Wedgetail	884	846
PW	O42	-117	-97
PW	Ot-38	-553	-514
PW	C35a	-257	-231
PW	C36a	-63	-51
PW	C36b	-378	-345
PW	C51b	-347	-315
PW	C57b	-579	-543
PW	C58a	-759	-710
PW	C86a	-576	-534
IWG	Th. Intermedium	-490	-469
IWG	Dundas	132	61

Table A.4.11 Net Present Values from the Cowra 2009 Trial

PW or IWG	Line ID	NPV at 8% Discount	NPV at 12% Discount
PW	C27a&b	-464	-438
PW	C31a	-351	-336
PW	C31b	-515	-489
PW	C33a	-495	-468
PW	C33b	-427	-407
PW	C34b	-544	-517
PW	C36a	-293	-280
PW	C36b	-240	-229
PW	C39b	127	123
PW	C40a	-497	-475
PW	C42b	-466	-442
PW	C44b	-408	-391
PW	C46a	-138	-130
PW	C47b	33	27
PW	C49b	-516	-492
PW	C51a	-548	-520
PW	C57b	-606	-576
PW	C58b	-561	-532
PW	C64a	534	515
PW	C79a	-223	-215
PW	C80a	-497	-473
PW	C80b	-367	-350
PW	C81b	-448	-426
PW	C88a	-630	-599
PW	C91b	-537	-510
PW	Ot-38	-143	-140
PW	O42	34	38
PW	TAF46	-420	-404
IWG	Dundas	-27	-56

Table A.4.12 Net Present Values from the Woodstock Trial

PW or IWG	Line ID	NPV at 8% Discount	NPV at 12% Discount
PW	C35a	-346	-337
PW	C36a	-471	-456
PW	C36b	-472	-456
PW	C44a	-222	-215
PW	C51b	-446	-432
PW	C64a	-401	-387
PW	C68a	-399	-386
PW	C68b	-415	-402
PW	C69b	-428	-414
PW	C71b	-357	-347
PW	C86b	-473	-457
PW	O42	-410	-398
PW	Ot-38	-435	-422
PW	Zhong1	-361	-349
IWG	Dundas	-392	-383

Table A.4.13 Annualized Net Returns from the Cowra 2008 Trial (AUS $/Ha)

PW, AW, or IWG	Line ID	Net Return
AW	Wedgetail	343
PW	O42	-46
PW	Ot-38	-215
PW	C35a	-100
PW	C36a	-25
PW	C36b	-147
PW	C51b	-135
PW	C57b	-225
PW	C58a	-294
PW	C86a	-224
IWG	Th. Interm.	-190
IWG	Dundas	51

Table A.4.14 Annualized Net Returns from the Cowra 2009 Trial

PW or IWG	Line ID	Net Return
PW	C27a&b	-180
PW	C31a	-136
PW	C31b	-200
PW	C33a	-192
PW	C33b	-166
PW	C34b	-211
PW	C36a	-114
PW	C36b	-93
PW	C39b	49
PW	C40a	-193
PW	C42b	-181
PW	C44b	-158
PW	C46a	-54
PW	C47b	13
PW	C49b	-200
PW	C51a	-213
PW	C57b	-235
PW	C58b	-218
PW	C64a	207
PW	C79a	-87
PW	C80a	-193
PW	C80b	-142
PW	C81b	-174
PW	C88a	-244
PW	C91b	-209
PW	Ot-38	-55
PW	O42	13
PW	TAF46	-163
IWG	Dundas	-10

Table A.4.15 Annualized Net Returns from the Woodstock Trial

PW or IWG	Line ID	Net Return
PW	C35a	-134
PW	C36a	-183
PW	C36b	-183
PW	C44a	-86
PW	C51b	-173
PW	C64a	-156
PW	C68a	-155
PW	C68b	-161
PW	C69b	-166
PW	C71b	-138
PW	C86b	-184
PW	O42	-159
PW	Ot-38	-169
PW	Zhong1	-140
IWG	Dundas	-152

Table A.4.16 Comparative Breakeven Prices and Yield Gains from the Cowra 2008 Trial

PW, AW, or IWG	Line ID	Price (AUS $/ton)	Yield Gain (%)
PW	O42	752	153
PW	Ot-38	2261	662
PW	C35a	957	222
PW	C36a	694	134
PW	C36b	1252	322
PW	C51b	1160	291
PW	C57b	2570	766
PW	C58a	43374	14514
PW	C86a	2529	752
IWG	Th. Interm.	1751	490
IWG	Dundas	544	83

Table A.4.17 Comparative Breakeven Prices and Yield Gains from the Cowra 2009 Trial

PW or IWG	Line ID	Price ($/ton)	Yield Gain (%)
PW	C27a&b	2533	753
PW	C31a	1555	424
PW	C31b	3548	1095
PW	C33a	3072	935
PW	C33b	2107	610
PW	C34b	4607	1452
PW	C36a	1298	337
PW	C36b	1125	279
PW	C39b	589	98
PW	C40a	3112	948
PW	C42b	2567	765
PW	C44b	1933	551
PW	C46a	898	203
PW	C47b	670	126
PW	C49b	3587	1109
PW	C51a	4803	1518
PW	C57b	12358	4064
PW	C58b	5541	1767
PW	C64a	385	30
PW	C79a	1080	264
PW	C80a	3117	950
PW	C80b	1642	453
PW	C81b	2333	686
PW	C88a	36276	12122
PW	C91b	4319	1355
PW	Ot-38	907	205
PW	O42	670	126
PW	TAF46	2041	588
IWG	Dundas	736	148

Table A.4.18 Comparative Breakeven Prices and Yield Gains from the Woodstock Trial

PW or IWG	Line ID	Price ($/ton)	Yield Gain (%)
PW	C35a	2300	675
PW	C36a	7411	2397
PW	C36b	7425	2402
PW	C44a	1369	361
PW	C51b	5120	1625
PW	C64a	3296	1011
PW	C68a	3249	995
PW	C68b	3726	1155
PW	C69b	4199	1315
PW	C71b	2447	724
PW	C86b	7614	2465
PW	O42	3554	1097
PW	Ot-38	4497	1415
PW	Zhong1	2511	746
IWG	Dundas	3082	938

Table A.4.19 Comparative Breakeven Subsidy Payments for the Cowra 2008 Trial

PW, AW, or IWG	Line ID	Subsidy ($/ha)
PW	O42	388
PW	Ot-38	557
PW	C35a	443
PW	C36a	367
PW	C36b	490
PW	C51b	478
PW	C57b	568
PW	C58a	637
PW	C86a	566
IWG	Th. Interm.	533
IWG	Dundas	292

Table A.4.20 Comparative Breakeven Subsidy Payments for the Cowra 2009 Trial

PW or IWG	Line ID	Subsidy ($/ha)
PW	C27a&b	523
PW	C31a	479
PW	C31b	543
PW	C33a	535
PW	C33b	509
PW	C34b	554
PW	C36a	457
PW	C36b	436
PW	C39b	294
PW	C40a	536
PW	C42b	524
PW	C44b	501
PW	C46a	396
PW	C47b	330
PW	C49b	543
PW	C51a	555
PW	C57b	578
PW	C58b	560
PW	C64a	136
PW	C79a	429
PW	C80a	536
PW	C80b	485
PW	C81b	517
PW	C88a	587
PW	C91b	551
PW	Ot-38	398
PW	O42	330
PW	TAF46	506
IWG	Dundas	353

Table A.4.21 Comparative Breakeven Subsidy Payments for the Woodstock Trial

PW or IWG	Line ID	Subsidy ($/ha)
PW	C35a	477
PW	C36a	526
PW	C36b	526
PW	C44a	429
PW	C51b	516
PW	C64a	498
PW	C68a	498
PW	C68b	504
PW	C69b	509
PW	C71b	481
PW	C86b	526
PW	O42	502
PW	Ot-38	512
PW	Zhong1	483
IWG	Dundas	495

V. ENVIRONMENTAL VALUATION OF SOIL CONSERVATION TO FORM SUBSIDIES

The comparative breakeven analyses given in the last chapter did not link subsidy payments to valuation of the off-site environmental benefits generated by the perennial grains. In this chapter, a benefit transfer study places monetary values on reduced soil erosion, one of intermediate wheatgrass and perennial wheat's most important environmental benefits. The off-site environmental benefits that are external to a grower's decision-making process are then internalized by adding the environmental benefits' subsidy values to the annual gross margins of the Australian perennial wheat and intermediate wheatgrass lines. New comparative breakeven prices, yields and costs are found that take into account the subsidy payments that represent the off-site environmental values. The chapter concludes with a discussion of how perenniality impacts the profitability of the perennial grain lines from the three Australian wheat trials.

5.1 Benefit Transfer Study

Perennial wheat and intermediate wheatgrass may provide a few main environmental benefits including carbon sequestration, reduced soil erosion and decreased nitrate leaching. The purpose of this section is to provide values for soil conservation, one of these environmental benefits. Reduced soil erosion was chosen to be valued in this study because soil erosion is a problem in the wheat-growing region of New South Wales, the location that this case study focuses on, the availability of environmental benefit data and the expected size of the environmental value of reduced soil erosion. This benefit transfer study estimates monetary values for on-site and off-site environmental benefits of the perennial grains' reduction in soil erosion. The on-site benefits of erosion reduction are valued as avoided grain yield loss attributable to soil erosion reduction. The on-site values are given to advise growers on the private impacts of the reduction in erosion provided by the perennial grains. The off-site benefits are valued as avoided reservoir dredging costs, and could be the basis for potential subsidies that could be paid to growers for producing off-site environmental benefits. Erosion reduction is the only environmental benefit studied in this section. Future work thus needs to be done to estimate monetary values of the other main environmental benefits that perennial wheat and intermediate wheatgrass provide.

On and Off Site Impacts of Soil Erosion

Physical Impacts- On Site

The main physical impact of soil erosion on-site is a decrease in the amount of fertile soil that is available for the growth of crops. When farms experience soil erosion, they lose soil that is a necessity for the growth of all crops (Tegtmeier and Duffy 2004). Topsoil is the most valuable soil to crop growth, and is usually the first type of soil to erode. Soil erosion also greatly reduces the productivity of farmland; farms with extensive soil erosion may only be able to grow crops that require low soil fertility, or they may not be able to grow anything at all (Larney et al. 1995). Yields of crops grown in poor soils can decline, thereby reducing farmland productivity. So in order to have productive land with high-yielding crops, soil erosion cannot cause a large decrease in farmland soil fertility or quality.

Physical Impacts- Off Site

One of the main off-site impacts of soil erosion is the silting up of waterways, which leads to a number of other off-site issues such as dredging, impaired navigation, decreased recreation opportunities, decreased reservoir availability and ecosystem disruption. Hansen et al. claim that “sediment has been known to clog road and irrigation ditches, to fill navigation channels and to adversely affect various types of water-based recreation" (2002). So, soil erosion causes sediment to build up in a number of different waterways near to or miles away from the farm in which it came. Using boats to navigate waterways that contain excessive amounts of sediment can be very difficult and require specific machinery (Hansen et al. 2002). Many waterways and dam reservoirs must be dredged in order to remove the sediment that has built up from farmland erosion upstream over the years (Tegtmeier and Duffy 2004).

Soil erosion also makes water treatment processes more difficult; more intense or new treatment processes need to be implemented to clean water that contains extensive amounts of sediment (Holmes 1988). Additionally, a reduction in recreation opportunities and lake or reservoir capacities can occur with the increased siltation of waterways (Ralston and Park 1989). Ecosystems may also become disrupted from too much sediment in watersheds. Sediment can greatly hurt aquatic life, and impact other ecosystem processes and services that are essential to the maintenance of a healthy environment (Cangelosi et al. 2001).

Economic Impacts- On Site

The on-site impacts of soil erosion reduce crop yield, which negatively impacts a farmer's revenue. Erosion may also cause the value of the farmland to decrease. Farms with lower quality, eroded soil would not sell for prices that were as high as those of farms with high-quality, fertile, non-eroded soil (Palmquist and Danielson 1989). A lower level of profitability (through yield loss) and a lower farmland price are the two most important on-site economic impacts of soil erosion because they both reduce the economic wellbeing of farmers.

Economic Impacts- Off Site

The off-site physical impacts of soil erosion result in increased public costs and reduced public values. Hansen et al. explain that in the U.S. alone, sediment in waterways causes over $1.2 billion in damages to navigation annually (2002). Also, increased sediment leads to waterway dredging projects, each of which cost millions of dollars to plan and execute (Hansen et al. 2002). Additionally, water treatment costs greatly increase when water treatment plants have to clean water that is full of sediment. More complex treatments need to be conducted to get the water to a safe level, which generates greater costs (Holmes 1988). Reduction in lake or reservoir capacity also leads to increasing costs because cities need to find new areas to store the water that can no longer fit in their reservoirs. The reduction in recreation opportunities due to the closure of recreation areas decreases visitors' recreation values, thereby generating a loss in public benefits. Fishing also becomes more costly in cloudy waterways, and the value of fish may decline as the health of the aquatic life dwindles (Ralston and Park 1989). So, off-site impacts of soil erosion lead to decreased public values and increased public costs, and consequently reduce the economic wellbeing of society.

Methods

Two different methods were used to transfer estimates of the monetary value of reduced soil erosion from perennial wheat. First, values were found for grain yield losses that would be avoided if a grower were to switch from annual wheat to perennial wheat. Since erosion reduces soil fertility, over time annual wheat could produce a lower grain yield than perennial wheat because annual wheat generates more erosion. Annual wheat generates more erosion because it has smaller root systems and requires more tillage than perennial wheat and intermediate wheatgrass. Second, reduced reservoir dredging costs were adapted from prior studies to value one of perennial wheat's off-site impacts of erosion reduction. Since soil erosion can lead to the sedimentation of reservoirs that require dredging, dredging can be reduced if soil erosion is reduced. Therefore, the growth of perennial grains could reduce dredging costs. The perennial grains' reduced dredging costs are then used as potential subsidy payments since a reduction in reservoir dredging would be an off-site environmental benefit.

Erosion Amounts

Erosion amounts were computed for annual wheat and perennial wheat at three different levels of soil erodibility: low, medium and high. The universal soil loss equation (USLE) was used to come up with measures of erosion for perennial wheat and annual wheat at the three levels of erodibility (Stone and Hilborn 2000). The USLE is built upon four variables: R for rainfall and runoff, K for erodibility, LS for the slope-length gradient of the piece of land and C for crop management. The USLE multiplies each component together: R*K*LS*C, to find the total amount of erosion in tons per hectare that was produced by each type of crop (Stone and Hilborn 2000). The three levels of soil erodibility (high, medium and low) were determined by the R, K and LS components of the USLE.

The R and K factor estimates came directly from Mahmoudzadeh et al., 2002. Mahmoudzadeh's R and K factors were provided for wheat-growing farmland in New South Wales, Australia. The LS and C factors came from a Canadian study of the universal soil loss equation by Stone and Hilborn, 2000. Since perennial wheat is an experimental crop, a C value for perennial wheat was created by averaging the C values of annual wheat and pasture (since perennial wheat is a wheat-grass hybrid). So, Stone and Hilborn's wheat and pasture C values were averaged to form perennial wheat's C value (2000).

The LS component impacted the level of erodibility through the steepness of the plot's slope. The plot with the lowest level of slope steepness had the lowest level of soil erodibility (Mahmoudzadeh et al. 2002). The lowest level of erodibility also had the lowest K value. The K value at the low level of erodibility used in this study was 0.13, which was pretty close to 0.15, the K value for the same type of soil in a Canadian study (Mahmoudzadeh et al. 2002 and Stone and Hilborn 2000). So, the erosion amounts at each level of erodibility were determined by multiplying together the components of the USLE.

Once the erosion amounts were found for annual wheat and perennial wheat at high, medium and low erodibility, each amount of erosion was divided by two because Mahmoudzadeh et al. claim that the USLE over-estimates erosion amounts between one point seven and two point two times (2002). Mahmoudzadeh et al. explain why the erosion estimates found through the USLE must be reduced: "the predicted soil loss rates (are) higher than the measured sediment yields because no allowance has been made for sediment storage following initial erosion" (p. 78, 2002). So, since the USLE is used to estimate the amounts of erosion generated by perennial wheat and annual wheat, the estimates must be reduced in order to represent the actual amounts of soil erosion that would be measured. A sensitivity analysis that evaluates how the erosion amounts would be different if two did not divide the USLE estimates is given at then end of this section. The R, K, LS and C factors used to find perennial wheat and annual wheat's erosion amounts are given in tables 5.1.1 and 5.1.2 below.

Table 5.1.1 R, K, LS and C Values for Annual Wheat

Erodibility	R	K	LS	C
High	181.5	0.08	0.86	0.175
Medium	173	0.065	0.54	0.175
Low	173	0.065	0.38	0.175

Table 5.1.2 R, K, LS and C Values for Perennial Wheat

Erodibility	R	K	LS	C
High	181.5	0.08	0.86	0.047
Medium	173	0.065	0.54	0.047
Low	173	0.065	0.38	0.047

Avoided Yield Loss Values

Since annual wheat would generate more erosion than perennial wheat, the grain yield of the perennial wheat crop would be greater than the yield of the annual wheat crop in the long run. Estimates for the yield losses avoided through the growth of perennial wheat or intermediate wheatgrass were calculated through a number of steps. The estimates could be used to advise growers on the private impacts of perennial wheat's environmental benefits. However, the avoided yield loss values would not be included in any subsidy estimates because the avoided yield losses are on-site environmental benefits and the subsidies only include values of off-site benefits.

To form the avoided yield loss values, the erosion estimates in tons per hectare predicted through the USLE were first multiplied by the density of clay loam soil to convert the erosion estimates to volumetric form (cubic meters per hectare). Much of the soil in the wheat-growing region of NSW consists of clay loam, which has a density of 1.26 grams per cubic centimeter (Rivenshield and Bassuk 2007). So, the mass of predicted erosion in tons per hectare was multiplied by 1.26 to find the amounts of erosion in cubic meters per hectare.

Larney et al. performed a study in Alberta, Canada, where grain yields were found after different amounts of soil were removed from farm plots (1995). The grain yields in kilograms per hectare were found after the authors removed 0, 6, 12, 18 and 24 cubic meters of soil. A non-linear least squares regression of soil removal on grain yield with data from Larney et al. was estimated for a hyperbolic model. The hyperbolic model with the specific functional form given below was chosen because it allowed the grain yield of the wheat crops to decrease as soil removal increased, without the grain yield ever becoming zero. Once the parameters were estimated through the non-linear least squares regression and placed into the model, the fitted hyperbolic model became:

Yield (kg/ha) = 1277.7*[1-(14.57*Erosion)/(100*1+(14.57*Erosion/100))]. (8)

The parameters 1277.7 and 14.57 were both estimated through the non-linear least squares regression of grain yield on soil removal, using data from Larney et al. 1995.

The USLE-based differences in the amounts of erosion generated by annual wheat and perennial wheat at high, medium and low soil erodibility were then included in the hyperbolic model as the erosion variable. The predicted grain yield differences produced at each level of erosion were found. These yield differences were the yield losses avoided through growing one hectare of perennial wheat instead of annual wheat. The avoided yield loss amounts were then multiplied by the adjusted 2010 Australian feed wheat grain price, which was around 11 cents per kilogram, as described in the budget analyses given in the previous chapter. As described above, the 2010 Australian feed wheat grain price was found by adjusting historical feed wheat grain prices by the Australian consumer price index (ABS 2011). Multiplying the avoided yield loss amounts by the 2010 feed wheat inflation-adjusted trend price generated the total values of perennial wheat's avoided yield losses at high, medium and low erodibility.

Reduced Dredging Costs

One of the main off-site impacts of soil erosion is the buildup of sediment in waterways. In New South Wales, Australia, sediment from farmland erosion accumulates in reservoirs and reduces the efficiency of hydroelectric dams. Dredging is often necessary to remove the amassed sediment from the dam reservoirs. Since perennial wheat produces less soil erosion than annual wheat, one of the most important off-site benefits of perennial wheat is a reduction in the amount of soil that ends up in dam reservoirs, thereby reducing the amount of dredging that needs to be performed in NSW. Although there are many off-site impacts of a reduction in soil erosion, the reduction in reservoir dredging costs was chosen to be valued here because it could greatly impact New South Wales, which is the study site of this case study. Some of the other off-site benefits of soil conservation, such as decreased water treatment costs or increased fishing values, would not have as much of an impact on NSW as a reduction in reservoir dredging costs.

Once the erosion amount differences in cubic meters per hectare for perennial wheat and annual were estimated using the USLE methods described above, they were adjusted to form the amount of eroded soil that ends up being dredged from reservoirs. David Pimentel claims that worldwide, only two thirds of all soil that is eroded from cropland ends up in waterways (2006). So to find the amounts of erosion that would enter waterways, the differences in perennial wheat and annual wheat soil erosion amounts at high, medium and low erodibility were multiplied by two thirds. These erosion estimates thus represent the total soil erosion amounts that would not be dredged from a reservoir due to perennial wheat's reduction in erosion.

After finding the avoided dredging amounts, the dredging costs were estimated for Australia in 1991 and were adjusted to the 2010 price level using the Australian consumer price index (ABS 2011, a). Reservoir dredging costs were estimated to be four dollars per cubic meter of sediment in Australia in 1991 (Bruun and Willekes 1992). Using the average 1991 and 2010 consumer price indexes, the 2010 dredging cost was found to be seven dollars per cubic meter of sediment (ABS 2011, a). The erosion amounts that would not be dredged due to perennial wheat's reduction in erosion were thus multiplied by seven dollars per cubic meter to find the total values of the reduced dredging costs at high, medium and low erodibility. The values of reduced dredging costs then formed potential high, medium and low subsidy amounts that could be paid to growers of perennial grains for producing off-site environmental benefits.

Results

Erosion Amounts

The process described in the methods section above was used to find the amounts of erosion that one hectare of annual wheat and perennial wheat produced at low, medium and high levels of soil erodibility. Table 5.1.3 below provides the soil erosion amounts in tons per hectare produced by each type of crop, given each level of erodibility. Table 5.1.4 shows the erosion amounts in cubic meters per hectare at each level of erodibility. All of the erosion amounts directly impact the monetary values of perennial wheat's reduction in erosion. The results reflect the assumption that the growth of perennial wheat erodes less soil than annual wheat on a per hectare per year basis.

Table 5.1.3 Calculated Soil Erosion Amounts in New South Wales at the Field Edge (Tons/Ha/Yr)[3]

Level of Erodibility	Annual Wheat	Perennial Wheat
High	14.3	3.8
Medium	8.4	2.2
Low	5.5	1.5

Table 5.1.4 Calculated Soil Erosion Amounts in New South Wales at the Field Edge (Cubic Meters/Ha/Yr)

Level of Erodibility	Annual Wheat	Perennial Wheat	Difference
High	18.0	4.7	13.3
Medium	10.6	2.8	7.8
Low	6.9	1.8	5.1

Avoided Yield Loss Values (On-Site)

The values of the avoided grain yield losses were the on-site benefits of perennial wheat's reduction in soil erosion. Given the erosion amount differences, the grain yields increased as the soil erodibility decreased. So, the lowest level of erodibility had the highest grain yield given the erosion amount differences between annual wheat and perennial wheat. The grain yields in kilograms per hectare per year from the differences in erosion amounts between annual wheat and perennial wheat are given in table 5.1.5 below at each level of soil erodibility.

Table 5.1.5 Predicted Grain Yields Saved Under PW by Averting Erosion Produced Under AW (Kg/Ha/Yr)

Level of Erodibility	Grain Yield from Averting AW Erosion
High	435
Medium	597
Low	734

The grain yields were then multiplied by 11 cents per kilogram, the 2010 Australian price of feed wheat grain, to find the avoided yield loss values generated by perennial

[3] Two thirds of these soil erosion amounts is expected to enter waterways that need dredging (Pimentel 2006).

wheat's reduction in soil erosion. At low erodibility, the avoided yield loss value was $78 per hectare. At the medium level of erodibility, the avoided yield loss value was $63, and the value was $46 at the highest level of erodibility. The avoided yield loss values for perennial wheat's reduction in erosion are given in table 5.1.6 below.

Table 5.1.6 Predicted Values of Avoided Yield Loss from Erosion Due to Replacing AW by PW (2010 AUD/Ha/Yr)

Level of Erosion	Values
High	$46
Medium	$63
Low	$78

Reduced Dredging Costs (Off-Site)

The amounts of eroded soil that would not be dredged from reservoirs due to perennial wheat's reduction in soil erosion are given below in table 5.1.7. These amounts were found by multiplying the original erosion estimates in cubic meters per hectare by two thirds (per Pimentel 2006). The amounts of sediment that would avoid being dredging decreased as the level of soil erodibility decreased.

Table 5.1.7 Avoided Dredging Amounts of Replacing AW by PW (Cubic Meters/Ha/Yr)

Level of Erodibility	Sediment Amounts Not Dredged
High	8.9
Medium	5.2
Low	3.4

The avoided dredging amounts of sediment were multiplied by seven dollars per cubic meter to find the avoided dredging costs. These avoided costs provided by perennial wheat's reduction in soil erosion are given in table 5.1.8 below at high, medium and low soil erodibility. The highest level of erodibility also provided the highest amount of avoided dredging costs. So, the growth of one hectare of perennial wheat instead of annual wheat could decrease the cost of dredging reservoirs in NSW, Australia.

Table 5.1.8 Reduced Dredging Costs Due to Replacing AW by PW (2010 AUD/Ha/Yr)

Level of Erosion	**Values**
High	$59
Medium	$35
Low	$23

Only the values of the external (off-site) environmental benefit could be paid to a grower of a perennial grain through a subsidy since the public would not be willing to pay growers to provide themselves with on-site environmental benefits produced by an EB technology. Therefore, only the values of the reduced dredging costs are included below in potential subsidy amounts paid to growers of perennial grains. The impact of these subsidy amounts on the profitability of perennial wheat and intermediate wheatgrass lines is addressed in section 5.2.

Even though the values of the avoided grain yield losses were not included in the subsidy amounts, they could still be used to advise growers on the private monetary impacts of the environmental benefits provided by perennial grains. Since perennial wheat's reduction in soil erosion would decrease grain yield losses and thus provide private monetary values that could directly impact profitability, the environmental benefit would impact the grower's adoption decision. So even though the avoided yield loss values would not be included in the subsidy estimates because the public would not be willing to pay for private benefits that only aid growers, the avoided yield loss values would still help a grower decide whether or not to adopt perennial wheat and intermediate wheatgrass.

Sensitivity Analyses

Two main assumptions were made in this benefit transfer study that largely impacted the monetary values of perennial wheat's reduction in soil erosion. Both of the assumptions influenced the reduced reservoir dredging costs, meaning that they also affected the potential subsidy values. The two assumptions were that the erosion estimates found through the universal soil loss equation were divided by two, and that the sediment delivery estimates in the reduced dredging section were multiplied by two thirds. Together these two changes increased the reservoir dredging costs that would be avoided through the growth of perennial wheat. So, this section provides two sensitivity analyses that describe what the erosion amounts would be if the USLE estimates were not divided by two, and what the sediment delivery estimates would be if they were not multiplied by two thirds. These analyses were performed because not all soil erosion studies agree that the USLE amounts should be divided by two or that the sediment delivery estimates should be multiplied by two thirds.

USLE Erosion Amount Sensitivity Analysis

If the erosion amounts that were generated through the universal soil loss equation were not divided by two, following Mahmoudzadeh et al. 2002, all of the erosion estimates would be two times as large. Table 5.1.9 provides the erosion amounts in tons per hectare at high, medium and low soil erodibility for perennial wheat and annual wheat, assuming that the USLE estimates were not divided by two. Since the erosion amounts were used to generate the avoided yield loss values and the reduced reservoir dredging costs, those estimates would change if two did not divide the USLE erosion amounts. The reduced reservoir dredging costs would double, but the avoided yield loss values would not. Table 5.1.10 provides the avoided yield loss values at high, medium and low erodibility given erosion amounts that were not divided by two.

Table 5.1.9 Sensitivity Analysis: Doubled Soil Erosion Amounts (Tons/Ha/Yr)

Level of Erodibility	Annual Wheat	Perennial Wheat	Difference
High	28.6	7.6	21.0
Medium	16.8	4.5	12.3
Low	11.0	2.9	8.1

Table 5.1.10 Sensitivity Analysis: Avoided Yield Loss Values with Doubled Soil Erosion Amounts Due to Replacing AW by PW (2010 AUD/Ha/Yr)

Level of Erosion	Values
High	$28
Medium	$42
Low	$54

Sediment Delivery Sensitivity Analysis

If the estimates of eroded soil that enter a waterway were not multiplied by two thirds following Pimentel (2006), the sediment delivery estimates would also be larger. Increasing the sediment delivery estimates would in turn increase the reservoir dredging costs that would be avoided due to the growth of perennial wheat. Since the reduced reservoir dredging costs would be used as proxies for subsidies paid to growers for the production of off-site environmental benefits, not multiplying the sediment delivery amounts by two thirds would also increase the potential subsidy amounts. The sediment delivery amounts in cubic meters per hectare at high, medium and low soil erodibility not multiplied by two thirds are the same as those given above in table 5.1.4. They would simply be the soil erosion amounts provided by the universal soil loss equation given in cubic meters per hectare. If the sediment delivery amounts were not divided by two thirds, the avoided reservoir dredging costs would also increase. Table 5.1.11 shows the reservoir dredging costs that would be avoided through the growth of perennial wheat at high, medium and low erodibility, assuming that the sediment delivery estimates were not multiplied by two thirds. These estimates do not include the doubled erosion amounts described above.

Table 5.1.11 Sensitivity Analysis: Reduced Dredging Costs if All Eroded Sediment Reaches Waterways (2010 AUD/Ha/Yr)

Level of Erosion	Values
High	$89
Medium	$52
Low	$34

Future Work

Since this study only valued the benefits of reduced soil erosion generated by the growth of perennial grains, all of the perennial grains' environmental benefits should be valued in the future. Studies can be conducted to place values on both the carbon sequestration and reduced nitrate leaching benefits that could be provided by the growth of perennial wheat or intermediate wheatgrass. When both of these benefits are valued monetarily, a more complete estimation of all of the values of the perennial grains' environmental benefits would be found.

5.2 Budget Analyses With Subsidies

Changing the price, yield, subsidies or costs of the perennial wheat and intermediate wheatgrass lines alone may not make the lines breakeven with annual wheat. Consequently, a combined strategy that would change more than one of these components could be used. This section evaluates the comparative breakeven prices, yields and costs of the perennial grain lines that include three levels of subsidy payments. Since perennial grains generate external public benefits, subsidies could be paid to perennial grain growers to compensate the growers for providing the off-site benefits. The reduced dredging costs at high, medium and low erodibility, $59, $35 and $23 Australian dollars per hectare from table 5.1.8, were used as the subsidy amounts paid to growers of perennial grains. The subsidy values were added to the annual gross margins of every perennial grain line from the three Australian wheat trials to find the net present values, annualized net returns and comparative breakeven prices, yields and costs of each perennial grain line including the annual subsidy payments. This section thus evaluates combined strategies that would allow the perennial grain lines to breakeven with annual wheat.

Budget Components

In forming the budget analyses that included the subsidy payments, the costs and revenues from the original budget analyses did not change. The only components of the budgets that changed were the gross margins. Specifically, $59, $35 and $23 subsidies representing high, medium and low erodibility were added to the annual gross margins in each of the three wheat trials. So, the annual gross margins of the perennial wheat and intermediate wheatgrass lines increased respectively by each subsidy amount.

Net Present Values

Equation 2 was used to generate the net present values of the perennial wheat and intermediate wheatgrass lines that included the subsidies. Along with the five perennial wheat and intermediate wheatgrass lines that had positive NPV's without subsidies, five other perennial grain lines had positive NPV's with the addition of the high subsidy. Perennial grain lines O42 and C36a in the Cowra 2008 trial and C46a, Dundas and O38 in the Cowra 2009 trial all gained positive NPV's given the high subsidy level of $59 per hectare per year. At the medium and small subsidies, only two perennial grain lines gained positive NPV's. Line C36a from the Cowra 2008 trial and Dundas from the Cowra 2009 trial both had positive NPV's given the $35 and $23 subsidies. However, even at the high subsidy level, none of the perennial wheat or intermediate wheatgrass lines had an NPV that was as high as the NPV of the annual wheat line.

Including the five perennial grain lines that had positive NPV's without the subsidies, at the high subsidy level ten perennial wheat and intermediate wheatgrass lines had positive NPV's. At the medium and low subsidy levels, seven perennial grain lines had positive NPV's. All of the other perennial grain lines had negative net present values given the three subsidy payments. Altogether, none of the NPV's were as high as the net present value of the annual wheat line, meaning that even with the high, medium and low annual subsidies, none of the perennial grain lines were as profitable as annual wheat. The NPV's for each wheat line given the high, medium and low subsidies are provided in tables A.5.1, A.5.2 and A.5.3 in the appendix at the end of this chapter.

Comparative Breakeven Analysis With Soil Conservation Subsidies

The conceptual model described in chapter three was applied to the budget analyses that included the three different subsidy payments. The annualized net returns including the subsidies were found for all of the perennial wheat and intermediate wheatgrass lines, and were then compared to the net return of the annual wheat line that did not include the subsidies. The comparative breakeven prices, yields and costs that would be necessary for the profits of the wheat lines to be equal to the net return of the annual wheat line given the subsidies were also found.

Annualized Net Returns

The annualized net returns that included the subsidies were generated through Equation 3. The perennial grain lines that gained positive net present values through the subsidies also gained positive annualized net returns. So, ten perennial grain lines had positive net returns at the high subsidy while seven lines had positive net returns at the medium and low subsidies. Like the net present values, none of the annualized net returns of the perennial grain lines were as large as the net return of the annual wheat line. So, changes in price, yield or costs would still need to occur for the perennial grain lines to become as profitable as annual wheat. The annualized net returns of every line of perennial wheat and intermediate wheatgrass including the subsidies are given in tables A.5.4, A.5.5 and A.5.6 in the appendix.

Comparative Breakeven Yields

Since none of the perennial wheat or intermediate wheatgrass lines had annualized net returns that were as large as the net return of annual wheat given the subsidies, increases in grain yield could increase the profits of the varieties so that they would be equal to the net return of annual wheat. The equation used to calculate the average annual comparative breakeven yields including the subsidies was:

$$y_{CBS} = (NR_0 + c_N - \sigma_N)/p_N \qquad (9)$$

In equation 9, y_{CBS} is assumed to be the average annual comparative breakeven grain yield of perennial wheat or intermediate wheatgrass, NR_0 is the annual net return of annual wheat, and c_N, σ_N and p_N are the average annual variable costs of production, the annual subsidy payments and the original price of the perennial wheat and intermediate wheatgrass lines ($297/ton), respectively. This equation determined the average annual comparative breakeven grain yields of every perennial wheat and intermediate wheatgrass line in the three Australian wheat trials.

The ten perennial wheat and intermediate wheatgrass lines with the positive net returns given the large subsidy and the seven lines with the positive net returns given the medium and small subsidies would require the lowest comparative breakeven yields. The rest of the perennial wheat and intermediate wheatgrass lines, which all had negative net returns, would require much larger gains in grain yield for their profits to equal the net return of annual wheat. As the subsidy payments increased, the comparative breakeven yields of each wheat line decreased.

Given the medium subsidy level, the following yield gains would allow the seven perennial wheat and intermediate wheatgrass lines with positive net returns to become as profitable as annual wheat: 118% for C36a and 70% growth for Dundas in Cowra 2008, 87% for C39b, 112% for C47b and O42, 133% for Dundas and 22% for C64a in Cowra 2009. All of the other perennial grain lines, which had negative net returns, would require larger increases in yield to become as profitable as annual wheat given the medium subsidy level. The comparative breakeven yield gain percentages for every wheat line at each level of subsidy payment are given in tables A.5.7, A.5.8 and A.5.9 in the appendix at the end of the chapter. These yield gains are the minimum thresholds that perennial wheat and intermediate wheatgrass breeders or geneticists could focus on when improving the yields of the wheat lines. Improving the perenniality of the perennial wheat and intermediate wheatgrass lines, which is the number of years that each line survives, would also help to increase the total grain yields and would be important to justify subsidies for soil conservation that depends on perenniality.

Comparative Breakeven Prices

A wide range of grain prices would be needed in order for the perennial wheat and intermediate wheatgrass lines to become as profitable as annual wheat, given the $59, $35 and $23 subsidy payments. The comparative breakeven grain prices in Australian dollars per ton were generated through this equation:

$$p_{CBS} = (NR_0 + c_N - \sigma_N)/y_N \qquad (10)$$

In this equation, the comparative breakeven grain prices of the perennial grain lines with subsidies were assumed to be p_{CBS}. NR_0 was the annual net return of annual wheat, and c_N, σ_N and y_N were the average AVCP, annual subsidy payments and average annual grain yields of the perennial wheat and intermediate wheatgrass lines. Equation 10 thus calculated the comparative breakeven grain prices in dollars per ton by adding the AVCP and subtracting the annual subsidies from annual wheat's net return, and then dividing by the average annual grain yield of the perennial grain lines.

Given the medium subsidy payment, the prices that would allow the seven perennial grain lines with positive net returns to breakeven with annual wheat were: $646 per ton for C36a and $506 for Dundas in Cowra 2008, $554 for C39b, $630 for C47b and O42, $692 for Dundas and $362 for C64a in Cowra 2009. The comparative breakeven price with a soil conservation subsidy of line C64a was actually lower than the price of annual wheat grain, which was $372 per ton. Given the medium subsidy payment, achieving some of the comparative breakeven prices through grain quality improvements could actually be possible. So, it would be more feasible for the perennial grain lines to reach the comparative breakeven price thresholds with the subsidies than without them. The comparative breakeven prices of the perennial grain lines that had negative net returns were significantly higher than those of the lines that had positive net returns. The comparative breakeven prices of all of the perennial wheat and intermediate wheatgrass lines are given in tables A.5.10, A.5.11 and A.5.12 in the appendix.

The perennial wheat and intermediate wheatgrass grain was originally priced as feed wheat grain. If the quality of the grain could be increased through plant breeding or genetics, the price of the grain could also increase. However, it is not likely that the perennial grain price would ever increase much above the price of annual (food) wheat grain, unless the perennial grain was considered to be a specialty or 'niche' crop. It is assumed that since the price of annual wheat was 20% higher than the price of feed wheat, only the comparative breakeven prices that were less than 20% higher than the original feed wheat grain price would be feasible. Only line C64a, which actually had a lower comparative breakeven price given the medium subsidy than the price of the annual wheat grain, shows potential to break even with a subsidy, based on improved grain quality without yield gains or improved perenniality.

Comparative Breakeven Costs

Most of the comparative breakeven annual variable costs of production of the perennial wheat and intermediate wheatgrass lines were negative given the three subsidies. The equation that was used to find the average comparative breakeven annual variable costs of production with subsidies was:

$$c_{CBS} = (p_N \cdot y_N) - NR_0 + \sigma_N \quad (11)$$

In equation 11, c_{CBS} was assumed to be the average comparative breakeven AVCP of the perennial wheat and intermediate wheatgrass lines, NR_0 stood for the annual net return of annual wheat, and p_N, y_N and σ_N were the grain price in dollars per ton, average annual grain yield and annual subsidy payments of the perennial wheat and intermediate wheatgrass lines, respectively.

Given the high subsidy payment, Dundas in the Cowra 2008 trial and C64a in the Cowra 2009 trial had positive comparative breakeven costs. However, the costs were still too small to be economically feasible. At the medium and low subsidy levels, only line C64a had positive comparative breakeven costs, and they were again very small. The comparative breakeven annual variable costs of production of every other perennial grain line were negative at all of the subsidy levels. Negative costs are unrealistic as explained in chapter four, so the comparative breakeven costs that would be necessary for the perennial grain lines to breakeven with annual wheat would not be feasible or attainable, and are thus not provided here.

Wheat breeders should focus on improving other areas of the perennial wheat and intermediate wheatgrass crops and not focus primarily on reducing production costs, since the perennial grain shortfalls are too large to be made up by reduced costs alone. The analysis of the comparative breakeven budgets with subsidies given throughout this section has shown that improving the grain yield of the perennial grain lines would probably be the most practical way for the wheat lines to become as profitable as the annual wheat line. Improving the grain quality of line C64a in order to increase the grain price would also be feasible, since the comparative breakeven price of line C64a was less than the price of annual wheat grain. The next section discusses how perenniality impacts the profitability of the perennial grain lines from the three Australian wheat trials.

5.3 The Role of Perenniality in the Viability of Perennial Wheat

How long a perennial grain crop lives determines the line's level of perenniality. Perennial wheat and intermediate wheatgrass crops may be able to live for five years before needing to be replanted, so lines that live for three, four or five years have a greater level of perenniality than those that live for one or two years. The level of perenniality impacts the profitability of the perennial wheat and intermediate wheatgrass lines. Theoretically, the longer a wheat line lives, the larger its grain yield should be since more years of survival provide more opportunities for the lines to produce grain. The analysis below evaluates how perenniality impacts the grain yield and profit of the perennial grain lines from the three Australian wheat trials. The analysis determines that what should happen theoretically does not actually happen empirically.

Impact of Perenniality on Yield and Profit

The perennial nature of the perennial wheat and intermediate wheatgrass lines should impact the total grain yield and profits produced by each line. Theoretically, the more years that a perennial wheat line survives, the larger the line's grain yield and net returns should be. However, this positive relationship was not found within the Australian wheat data. The highest-yielding perennial wheat and intermediate wheatgrass lines did not survive as long as the long-living lines that produced lower yields. In fact, all of the perennial wheat and intermediate wheatgrass lines that had positive annualized net returns only lived for two years. In the three Australian wheat trials, the high-yielding lines died early while the longer-living lines had lower net returns.

Cowra 2008 Trial Results

Although the Cowra 2008 trial lasted for four years, most of the perennial wheat and intermediate wheatgrass lines in the trial only survived for two years. All 11 lines lived for two years, three lines lived for three years and only one line lived for all four years of the trial. Since a strongly perennial intermediate wheatgrass or perennial wheat line would live from three to five years, not very many of the lines from the Cowra 2008 trial lived up to their perennial potential.

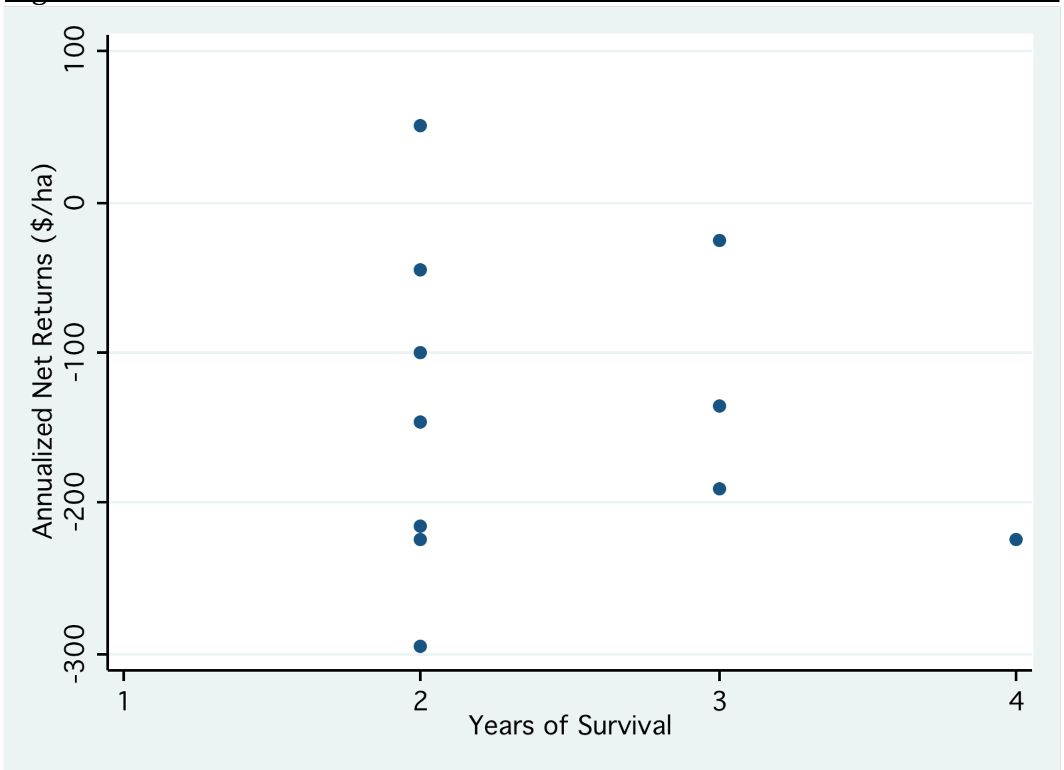
The grain yield and net returns of the lines in the Cowra 2008 trial did not increase as the years of survival increased. Dundas, the line that had the highest grain yield and net return in the Cowra 2008 trial, only survived for two years. The three lines that survived for three years had yields that were much lower than the grain yield of Dundas, and their net returns were all negative. Also, the one perennial wheat line that lived for four years, line C57b, had one of the lowest grain yields and annualized net returns out of every line in the trial. So, the higher-yielding lines only lived for two years and were not very perennial, while the lines that lived for three or four years and were thus more perennial produced smaller amounts of grain. This clearly shows that higher levels of perenniality did not lead to larger grain yields and profits, which was opposite of what was expected. The years of survival, total grain yield and annualized net returns of each perennial wheat and intermediate wheatgrass line from the Cowra 2008 trial are given in table 5.3.1 below.

Table 5.3.1 Survival, Yield and Annualized Net Returns of Cowra 2008 Trial

PW or IWG	Line ID	Years Survived	Total Yield (kg/ha)	Net Return (AU$/ha/yr)
PW	O42	2	242	-46
PW	Ot-38	2	808	-215
PW	C35a	2	1903	-100
PW	C36a	3	2668	-25
PW	C36b	2	1439	-147
PW	C51b	3	1554	-135
PW	C57b	4	749	-225
PW	C58a	2	43	-294
PW	C86a	2	707	-224
IWG	Th. Interm.	3	1183	-190
IWG	Dundas	2	4116	51

The graph below also shows that the wheat line with the highest annualized net return only lived for two years. The line with the second highest net return did live for three years, so increased perenniality could generate increased grain yield. However, that line still had a negative annualized net return, and the lines with the third and fourth highest net returns only lived for two years. So, the graph helps to show how more years of survival did not lead to higher grain yields and larger net returns for the Cowra 2008 trial.

Figure 5.3.1 Years of Survival vs. Annualized Net Returns of Cowra 2008 Trial



Cowra 2009 Trial Results

The Cowra 2009 trial lasted for three years, but most of the perennial grain lines only survived for two years. Every wheat line within the trial lived for two years, but only five varieties out of 29 survived for three years. So, only 17% of the perennial wheat and intermediate wheatgrass lines in the Cowra 2009 trial survived for the entire duration of the trial. The Cowra 2009 trial only lasted for three years because none of the perennial grain lines in the trial lived for more years than that.

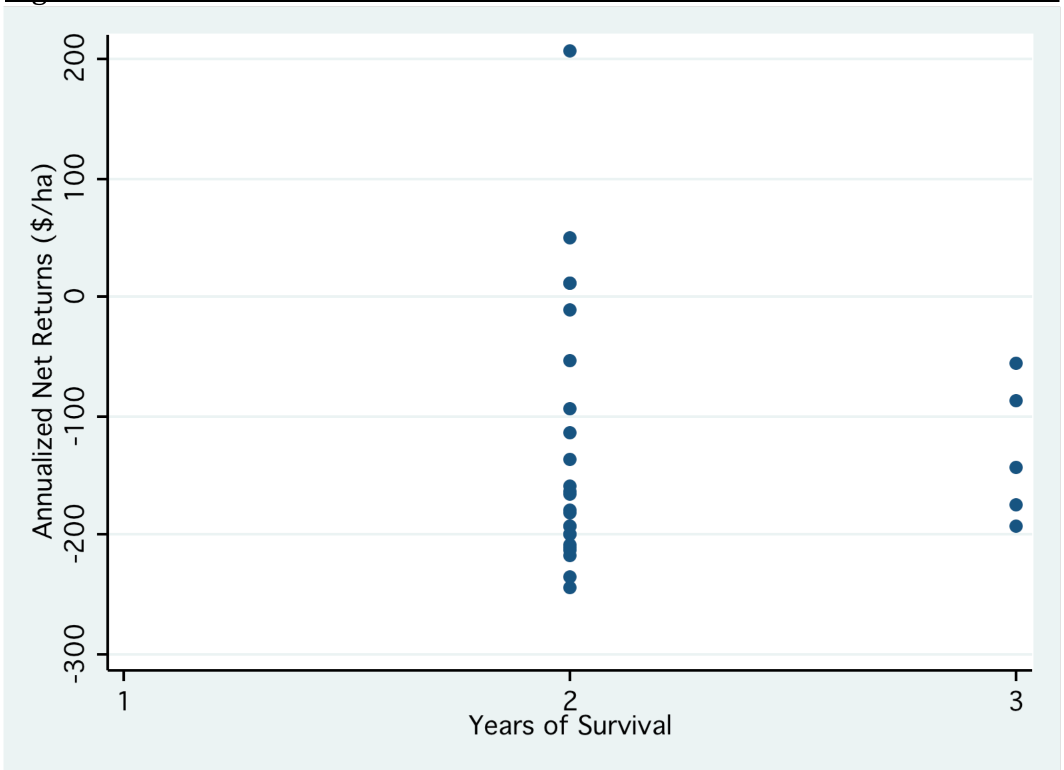
The same pattern with grain yield and annualized net returns that was seen in the Cowra 2008 trial was also seen in the Cowra 2009 trial. The four lines of perennial wheat that had positive net returns and the highest grain yields only lived for two years. Of the perennial wheat lines that survived for three years, none had a positive net return. So in the Cowra 2009 trial, perenniality did not lead to higher grain yields or net returns. Instead, the high-yielding wheat lines were closer to annual wheat because they produced a lot of grain early on, and then died off. The yields, net returns and years of survival for each perennial wheat and intermediate wheatgrass line in the Cowra 2009 trial are given in table 5.3.2 below.

A graph of the results from the Cowra 2009 trial like the one above for the Cowra 2008 trial is also given below. Figure 5.3.2 shows that in the second Cowra trial, the perennial wheat and intermediate wheatgrass lines with the highest yields and net returns again survived for only two years. The four perennial wheat lines that had the highest net returns all lived for only two years, as shown by the four highest points above the two-year mark in the graph. The graph shows that every perennial wheat and intermediate wheatgrass line that lived for three years had a negative net return.

Table 5.3.2 Survival, Yield and Annualized Net Returns of Cowra 2009 Trial

PW or IWG	Line ID	Years Survived	Total Yield (kg/ha)	Net Return (AU$/ha/yr)
PW	C27a&b	2	651	-$180
PW	C31a	2	1112	-$136
PW	C31b	2	481	-$200
PW	C33a	2	537	-$192
PW	C33b	2	814	-$166
PW	C34b	2	370	-$211
PW	C36a	2	1322	-$114
PW	C36b	2	1519	-$93
PW	C39b	2	2871	$49
PW	C40a	2	569	-$193
PW	C42b	2	656	-$181
PW	C44b	2	906	-$158
PW	C46a	2	1884	-$54
PW	C47b	2	2577	$13
PW	C49b	2	488	-$200
PW	C51a	2	343	-$213
PW	C57b	2	140	-$235
PW	C58b	2	298	-$218
PW	C64a	2	4353	$207
PW	C79a	3	1598	-$87
PW	C80a	3	547	-$193
PW	C80b	3	1051	-$142
PW	C81b	3	730	-$174
PW	C88a	2	48	-$244
PW	C91b	2	385	-$209
PW	Ot-38	3	1914	-$55
PW	O42	2	2492	$13
PW	TAF46	2	870	-$163
IWG	Dundas	2	2592	-$10

Figure 5.3.2 Years of Survival vs. Annualized Net Returns of Cowra 2009 Trial



Woodstock Trial Results

Not much can be said about how perenniality influenced the grain yields and net returns of the perennial wheat and intermediate wheatgrass lines in the Woodstock trial. Unlike the Cowra 2008 and 2009 trials, the Woodstock trial only lasted for two years. All 15 of the perennial wheat and intermediate wheatgrass lines that were included in the trial survived the entire length of the two-year trial. Every wheat line in the Woodstock trial had a negative net return each year from producing very moderate grain yields. Since the trial did not last more than two years, the yields and net returns of any lines that survived more years could not be compared. The information that came from Hayes et al. did not explain if any of the perennial wheat lines lived longer than two years in the Woodstock trial (2012).

Regressions of Years of Survival on Net Returns

Two regressions of the perennial wheat and intermediate wheatgrass lines' years of survival on their annualized net returns were performed to evaluate the impact of perenniality on profitability. For the Cowra 2008 and 2009 trials, dummy variables were formed for every year that the intermediate wheatgrass and perennial wheat lines survived. The dummy variable was a one if the wheat line survived during that year, and a zero if the line did not survive that year. In the two regressions, the first and second years of survival were left out so that those years were the base case. So, the constant term reflects the impact of two years of survival on the annualized net returns, since every perennial grain line lived for two years. The coefficients of the other survival year dummy variables represented the deviations away from the years one and two base case.

The equation representing the two regressions of years of survival on annualized net returns was:

$$ANR = \beta_0 + \beta_2 DV_3 + \beta_3 DV_4 \qquad (12)$$

In equation 12, the annualized net returns are given by ANR, and they are impacted by the dummy variables for each year of survival and their parameters. β_0 is the constant term and is the coefficient for years one and two of survival. DV_3 and DV_4 are the dummy variables representing survival in years three and four, and β_2 and β_3 are the coefficients of the dummy variables for both of those years. So using equation 12, regressions were formed for years of survival on annualized net returns for the Cowra 2008 and 2009 trials. A regression was not performed for the Woodstock trial since the trial only lasted for two years and the perennial wheat and intermediate wheatgrass lines were consequently not very perennial. The results of the regressions for the Cowra 2008 and 2009 wheat trials are given below.

Cowra 2008 and 2009 Regression Results

Table 5.3.3 given below shows the constant terms and coefficients of the dummy variable regressions for both of the Cowra trials. In most of the cases, more years of survival actually decreased the annualized net return of the perennial wheat and intermediate wheatgrass lines. Year three of the Cowra 2008 trial would increase the net return of the wheat lines, but taken together with the years one and two base case, year three would still have a negative impact on the net returns of the perennial wheat and intermediate wheatgrass lines.

Table 5.3.3 Effect of Perenniality on Annualized Net Returns: Regression Coefficients from the Cowra 2008 and 2009 Trials

Trial	Years 1 and 2	Year 3	Year 4	R^2 Values
Cowra 2008	-139	22.6	-108	0.08
T-statistics	-3.33	0.30	-0.85	
Cowra 2009	-129	-1.59	--	0.00
T-statistics	-5.99	-0.03	--	

In the Cowra 2008 trial, two years of survival led to negative annualized net returns of (-$139) per hectare. Since the first two years of survival were associated with negative annualized net returns, the perennial grain lines would not be profitable. The annualized net return of (-$139) for years one and two was statistically significant at a 95% level. The third and fourth years of survival in the Cowra 2008 trial had coefficients that were not statistically different from zero at a 95% level.

In the Cowra 2009 trial, years one and two generated an annualized net return that was (-$129) per hectare. The constant term of years one and two was statistically significant at the 95% level. So, like the Cowra 2008 trial, the growth of the perennial grain lines would not be profitable in the Cowra 2009 trial. The coefficient of year three was not statistically significant at 95%, meaning that the coefficient was not significantly different than zero. No results are shown for year four because the Cowra 2009 trial only lasted for three years. Overall, the regression results signal that perenniality did not increase the annualized net returns in the perennial grain lines tested at Cowra.

Impact of Perenniality on Environmental Benefits

Low levels of perenniality would not only impact the profitability of perennial grains; lower perenniality would also lead to decreased production of environmental benefits. Since perennial wheat and intermediate wheatgrass are believed to produce environmental benefits like reduced soil erosion, carbon sequestration and decreased nitrate leaching every year, the more years that the crops survive, the greater will be the amounts of environmental benefits that are produced. Perennial grain lines that only live for one or two years would produce smaller amounts of environmental benefits than lines that would live for three, four or five years. Because of this, perenniality could also impact the policy justification for paying subsidies to growers of perennial grains. Since perennial wheat and intermediate wheatgrass produce more environmental benefits the longer they live, subsidies could be paid to growers based on the number of years that the grain crops grow. So, perenniality impacts the profitability and environmental benefits of perennial wheat and intermediate wheatgrass, and may also influence the subsidies paid to perennial grain growers.

5.4 Conclusion

This benefit transfer section calculated on and off-site values of perennial wheat's reduction in soil erosion, and the predicted off-site values were used as potential subsidy payment amounts. However, when using the off-site values of reduced erosion as the subsidies, changes in price, yield or costs would still need to occur to make the perennial wheat and intermediate wheatgrass lines from the three Australian wheat trials as profitable as annual wheat. Increasing the quality of the wheat grain (associated with price) could be feasible given the subsidy payments in one instance. Perennial wheat line C64a would have a comparative breakeven grain price close to the annual wheat grain price, which could be reached through grain quality improvements. However, reducing the annual variable costs of production would not be feasible because almost all of the perennial grain lines would require the annual costs to be negative, even with the subsidy payments.

Increasing the grain yields of the perennial grain lines could also allow the lines to breakeven with annual wheat. Given the subsidy payments, the comparative breakeven yield gains of the perennial grain lines with positive annualized net returns would be feasible to attain through plant breeding or genetics. However, increasing the perenniality of the lines would not allow the perennial grain lines to breakeven with annual wheat. The empirical analysis given above showed that increased perenniality did not lead to higher annualized net returns. So, given the subsidies of $59, $35 and $23 Australian dollars per hectare per year, increasing the grain quality for better price and especially the yields of the perennial grain lines would be the most feasible changes for the perennial grain lines to breakeven with annual wheat. Changing the annual variable costs of production of the perenniality of the perennial grain lines would not allow the lines to become as profitable as annual wheat.

APPENDIX

CHAPTER FIVE APPENDIX

Table A.5.1 Net Present Values with Subsidies from the Cowra 2008 Trial (AUS$/ha)

PW or IWG	Line ID	With $59 Subsidy	With $35 Sub	With $23 Sub
PW	O42	78	-2	-41
PW	Ot-38	-358	-437	-477
PW	C35a	-62	-141	-181
PW	C36a	132	53	13
PW	C36b	-183	-262	-302
PW	C51b	-152	-231	-271
PW	C57b	-384	-463	-503
PW	C58a	-563	-643	-683
PW	C86a	-381	-460	-500
IWG	Th. Interm.	-294	-374	-414
IWG	Dundas	328	248	209

Table A.5.2 Net Present Values with Subsidies from the Cowra 2009 Trial (AUS$/ha)

PW or IWG	Line ID	With $59 Subsidy	With $35 Sub	With $23 Sub
PW	C27a&b	-312	-373	-404
PW	C31a	-199	-261	-292
PW	C31b	-363	-425	-455
PW	C33a	-343	-405	-436
PW	C33b	-275	-337	-368
PW	C34b	-392	-454	-485
PW	C36a	-141	-203	-234
PW	C36b	-88	-150	-180
PW	C39b	279	217	186
PW	C40a	-345	-407	-438
PW	C42b	-314	-376	-407
PW	C44b	-256	-318	-349
PW	C46a	14	-48	-79
PW	C47b	186	124	93
PW	C49b	-364	-426	-457
PW	C51a	-396	-458	-489
PW	C57b	-454	-516	-546
PW	C58b	-409	-470	-501
PW	C64a	686	624	593
PW	C79a	-71	-133	-164
PW	C80a	-345	-407	-438
PW	C80b	-214	-276	-307
PW	C81b	-296	-358	-389
PW	C88a	-478	-540	-571
PW	C91b	-385	-446	-478
PW	Ot-38	9	-53	-84
PW	O42	186	124	93
PW	TAF46	-268	-330	-361
IWG	Dundas	125	63	33

Table A.5.3 Net Present Values with Subsidies from the Woodstock Trial (AUS$/ha)

PW or IWG	Line ID	With $59 Subsidy	With $35 Sub	With $23 Sub
PW	C35a	-241	-283	-305
PW	C36a	-366	-409	-430
PW	C36b	-366	-409	-430
PW	C44a	-117	-159	-181
PW	C51b	-341	-384	-405
PW	C64a	-296	-338	-360
PW	C68a	-294	-337	-358
PW	C68b	-310	-353	-374
PW	C69b	-323	-366	-387
PW	C71b	-252	-294	-316
PW	C86b	-368	-411	-432
PW	O42	-305	-348	-369
PW	Ot-38	-330	-372	-394
PW	Zhong1	-256	-299	-320
IWG	Dundas	-287	-330	-351

Table A.5.4 Annualized Net Returns with Subsidies from the Cowra 2008 Trial (AUS$/ha)

PW or IWG	Line ID	With $59 Subsidy	With $35 Sub	With $23 Sub
PW	O42	30	-1	-16
PW	Ot-38	-139	-170	-185
PW	C35a	-24	-55	-70
PW	C36a	51	20	5
PW	C36b	-71	-102	-117
PW	C51b	-59	-90	-105
PW	C57b	-149	-180	-195
PW	C58a	-219	-250	-265
PW	C86a	-148	-179	-194
IWG	Th. Interm.	-114	-145	-161
IWG	Dundas	127	96	81

Table A.5.5 Annualized Net Returns with Subsidies from the Cowra 2009 Trial (AUS$/ha)

PW or IWG	Line ID	With $59 Subsidy	With $35 Sub	With $23 Sub
PW	C27a&b	-121	-145	-157
PW	C31a	-77	-101	-113
PW	C31b	-141	-165	-177
PW	C33a	-133	-157	-169
PW	C33b	-107	-131	-143
PW	C34b	-152	-176	-188
PW	C36a	-55	-79	-91
PW	C36b	-34	-58	-70
PW	C39b	108	84	72
PW	C40a	-134	-158	-170
PW	C42b	-122	-146	-158
PW	C44b	-99	-123	-135
PW	C46a	6	-19	-31
PW	C47b	72	48	36
PW	C49b	-141	-165	-177
PW	C51a	-154	-178	-190
PW	C57b	-176	-200	-212
PW	C58b	-159	-183	-195
PW	C64a	266	242	230
PW	C79a	-28	-52	-64
PW	C80a	-134	-158	-170
PW	C80b	-83	-107	-119
PW	C81b	-115	-139	-151
PW	C88a	-185	-209	-221
PW	C91b	-150	-174	-186
PW	Ot-38	4	-20	-32
PW	O42	72	48	36
PW	TAF46	-104	-128	-140
IWG	Dundas	49	25	13

Table A.5.6 Annualized Net Returns with Subsidies from the Woodstock Trial (AUS$/ha)

PW or IWG	Line ID	With $59 Subsidy	With $35 Sub	With $23 Sub
PW	C35a	-93	-110	-118
PW	C36a	-142	-159	-167
PW	C36b	-142	-159	-167
PW	C44a	-45	-62	-70
PW	C51b	-132	-149	-157
PW	C64a	-115	-131	-140
PW	C68a	-114	-131	-139
PW	C68b	-120	-137	-145
PW	C69b	-125	-142	-150
PW	C71b	-98	-114	-123
PW	C86b	-143	-159	-168
PW	O42	-118	-135	-143
PW	Ot-38	-128	-145	-153
PW	Zhong1	-99	-116	-124
IWG	Dundas	-111	-128	-136

Table A.5.7 Comparative Breakeven Yield Gains with Subsidies for Cowra 2008 Trial (growth %/line)

PW or IWG	Line ID	With $59 Subsidy	With $35 Sub	With $23 Sub
PW	O42	123	136	142
PW	Ot-38	572	608	627
PW	C35a	184	200	208
PW	C36a	106	118	123
PW	C36b	272	292	303
PW	C51b	245	264	273
PW	C57b	663	705	726
PW	C58a	12787	13489	12840
PW	C86a	651	692	713
IWG	Th. Interm.	420	449	463
IWG	Dundas	62	70	75

Table A.5.8 Comparative Breakeven Yield Gains with Subsidies for Cowra 2009 Trial (%/line)

PW or IWG	Line ID	With $59 Subsidy	With $35 Sub	With $23 Sub
PW	C27a&b	668	703	720
PW	C31a	372	393	404
PW	C31b	976	1025	1049
PW	C33a	832	874	895
PW	C33b	539	568	582
PW	C34b	1298	1361	1392
PW	C36a	294	311	320
PW	C36b	241	257	264
PW	C39b	79	87	91
PW	C40a	844	886	908
PW	C42b	679	714	731
PW	C44b	486	513	526
PW	C46a	172	185	191
PW	C47b	103	112	117
PW	C49b	988	1037	1062
PW	C51a	1357	1423	1455
PW	C57b	3649	3818	3902
PW	C58b	1581	1656	1694
PW	C64a	17	22	25
PW	C79a	228	242	250
PW	C80a	845	888	909
PW	C80b	398	421	432
PW	C81b	608	640	656
PW	C88a	10903	11400	11648
PW	C91b	1210	1269	1298
PW	Ot-38	175	187	194
PW	O42	103	112	117
PW	TAF46	519	547	561
IWG	Dundas	123	133	138

Table A.5.9 Comparative Breakeven Yield Gains with Subsidies for Woodstock Trial (%/line)

PW or IWG	Line ID	With $59 Subsidy	With $35 Sub	With $23 Sub
PW	C35a	617	641	652
PW	C36a	2211	2287	2324
PW	C36b	2215	2291	2329
PW	C44a	327	341	348
PW	C51b	1497	1549	1575
PW	C64a	928	961	978
PW	C68a	913	946	963
PW	C68b	1062	1100	1119
PW	C69b	1209	1252	1274
PW	C71b	663	688	700
PW	C86b	2274	2352	2391
PW	O42	1008	1044	1063
PW	Ot-38	1302	1348	1371
PW	Zhong1	683	709	721
IWG	Dundas	861	892	908

Table A.5.10 Comparative Breakeven Prices with Subsidies for Cowra 2008 Trial ($/ton)

PW or IWG	Line ID	With $59 Subsidy	With $35 Sub	With $23 Sub
PW	O42	663	700	717
PW	Ot-38	1994	2102	2157
PW	C35a	844	890	913
PW	C36a	612	646	662
PW	C36b	1104	1165	1195
PW	C51b	1023	1079	1107
PW	C57b	2266	2390	2451
PW	C58a	38248	40333	41376
PW	C86a	2230	2352	2413
IWG	Th. Interm.	1544	1628	1670
IWG	Dundas	480	506	519

Table A.5.11 Comparative Breakeven Prices with Subsidies for Cowra 2009 Trial ($/ton)

PW or IWG	Line ID	With $59 Subsidy	With $35 Sub	With $23 Sub
PW	C27a&b	2281	2383	2435
PW	C31a	1400	1463	1495
PW	C31b	3194	3338	3410
PW	C33a	2766	2891	2953
PW	C33b	1897	1982	2025
PW	C34b	4148	4335	4428
PW	C36a	1169	1221	1248
PW	C36b	1013	1058	1081
PW	C39b	530	554	566
PW	C40a	2802	2928	2991
PW	C42b	2311	2415	2467
PW	C44b	1740	1818	1858
PW	C46a	809	845	863
PW	C47b	603	631	644
PW	C49b	3230	3375	3448
PW	C51a	4324	4519	4616
PW	C57b	11127	11628	11878
PW	C58b	4989	5213	5326
PW	C64a	347	362	370
PW	C79a	973	1016	1038
PW	C80a	2806	2923	2996
PW	C80b	1478	1545	1578
PW	C81b	2101	2196	2243
PW	C88a	32661	34132	34867
PW	C91b	3888	4063	4151
PW	Ot-38	816	853	871
PW	O42	603	630	644
PW	TAF46	1837	1920	1961
IWG	Dundas	662	692	707

Table A.5.12 Comparative Breakeven Prices with Subsidies for Woodstock Trial ($/ton)

PW or IWG	Line ID	With $59 Subsidy	With $35 Sub	With $23 Sub
PW	C35a	2128	2198	2233
PW	C36a	6858	7083	7196
PW	C36b	6871	7096	7209
PW	C44a	1267	1308	1329
PW	C51b	4739	4894	4972
PW	C64a	3050	3150	3200
PW	C68a	3007	3105	3154
PW	C68b	3448	3561	3617
PW	C69b	3886	4013	4077
PW	C71b	2264	2339	2376
PW	C86b	7046	7277	7392
PW	O42	3289	3397	3450
PW	Ot-38	4162	4298	4366
PW	Zhong1	2324	2400	2438
IWG	Dundas	2852	2946	2992

VI. THESIS CONCLUSION

Since the public's agricultural demands have changed from high-input, high-yielding technologies to environmentally beneficial technologies since the mid 1900's, the economic feasibility of both types of technologies must be evaluated. The economic model described in chapter three explained how to examine the profits of an environmentally beneficial technology compared to the net returns of a conventional technology. If we assume that producers strictly prefer profitability to environmental benefits, then an EB agricultural technology can only be adopted if the profit of the technology were to be greater than or equal to the net return of the conventional technology that is already established.

A comparative breakeven profitability analysis was applied to 43 lines of perennial wheat and two lines of intermediate wheatgrass compared to one line of annual wheat from three wheat trials in New South Wales, Australia. None of the perennial wheat or intermediate wheatgrass lines were as profitable as annual wheat, so changes would need to be made to the price, yield, costs or subsidies of the wheat lines to increase the lines' profitability. Potential subsidy estimates were generated using benefit transfer methods by valuing the off-site benefits of reduced soil erosion that could potentially be provided by the perennial grains. The off-site reduced dredging costs were used as the subsidy estimates that could be paid to growers. However, even with the $59, $35 and $23 Australian dollar per hectare subsidy payments, none of the perennial grain lines were as profitable as the annual wheat line. So even if subsidies were available at these levels, changes would need to be made for the wheat lines to become as profitable as annual wheat.

The five characteristics of the perennial wheat and intermediate wheatgrass lines that could be altered to increase profitability were: price (through improving grain quality), yield (through grain quantity), costs, subsidies and perenniality. Out of these five characteristics, perennial wheat breeders and geneticists should focus on improving grain quantity (yield) and grain quality (price). These two characteristics provide the most feasible options for increasing the profits of the perennial wheat and intermediate wheatgrass lines. The addition of subsidy payments would also be a good option; however, subsidy payments would need to be accompanied with a change in price or yield in order for perennial wheat and intermediate wheatgrass to become as profitable as annual wheat.

With or without the subsidies, perennial wheat line C64a would have a comparative breakeven price close to the price of the annual wheat grain. So, if plant breeders or geneticists improved the quality of the grain of line C64a, the grain price could increase to allow C64a to become as profitable as annual wheat. However, the comparative breakeven prices of the other perennial grain lines are much higher than those of line C64a, so they would not become adoptable by profit-maximizing growers through grain quality improvements alone.

Increasing the grain yields of the perennial grain lines would be the most promising route for the profits of the lines to equal the net return of the annual wheat line. With or without the subsidy payments, the yield gains of the perennial grain lines with positive annualized net returns could be achieved through genetic improvements or wheat breeding. During the Green Revolution, specifically between 1960 and 1990, the grain yield of annual wheat crops increased between two and three times what it was before the Green Revolution (Khush 1999). Since huge increases in the grain yield of annual wheat crops occurred during the Green Revolution, increases in the grain yields of perennial wheat and intermediate wheatgrass lines could conceivably be feasible as well.

Subsidies could be used to increase the profitability of the perennial grain lines. However, implementing subsidies alone would not allow the profits of the perennial grain lines to equal the net return of the annual wheat line. The comparative breakeven subsidies far exceed the levels that would cover soil conservation benefits from perennial grains. But a subsidy payment together with a price or yield increase would be able to generate breakeven profitability for the perennial grain lines.

Changes in costs would not be economically feasible to make the perennial wheat and intermediate wheatgrass lines as profitable as annual wheat. With or without the subsidy payments, almost all of the perennial wheat and intermediate wheatgrass lines had negative comparative breakeven costs. This means that most of the perennial grain lines would have to have negative annual variable costs of production to become as profitable as annual wheat, which is unrealistic.

Relying on increases in perenniality to improve the profitability of the perennial grain lines would also be unrealistic. The empirical analysis that showed the impact of years of survival on annualized net returns determined that increased perenniality did not lead to increased annualized net returns for the perennial grain lines in the Australian wheat trials. So, increasing the number of years that the perennial grain lines survive would not encourage the lines to breakeven with annual wheat.

In summary, increasing grain quality (and hence price) or grain yield ideally with a subsidy covering external environmental benefits, and not decreasing the costs or increasing the perenniality, would be the most feasible options to enable the perennial grain lines to break even with annual wheat. If these three characteristics could be altered, perennial wheat and intermediate wheatgrass would have the potential to become as profitable as annual wheat.

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