# An Economic Analysis of the Potential for Carbon Credits to Improve Profitability of Conservation Tillage Systems Across Washington State

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Building on the modeling results obtained through CropSyst, this analysis examines the efficacy of carbon subsidies for encouraging farmers to adopt reduced tillage systems. Representative farms were developed for four study locations, three representing different rainfall zones of the dryland areas of Washington (Lind, St. John, and Pullman), and one representing irrigated areas of the Columbia Basin (Paterson). Detailed enterprise budgets were created for each tillage regime on representative farms for each area. Profitability by tillage regime for each location was analyzed. Finally, an optimization program was used to determine levels of carbon credits sufficient to induce adoption of reduced tillage systems in Washington's major farming regions at this point in time.

## Representative Farms

A representative, or typical, farm was created for each location. The enterprise budgets created for each tillage regime are meant to be viewed as characteristic; they are not a mathematical average of a large number of producers. Costs and returns will differ significantly if farm size, machinery complement, productivity, etc., vary from the assumptions for these representative farms. Detailed budgets are available in appendices 24A-24H.

At the Lind site, low precipitation averaging about 10" (254 mm) per year and occurring primarily in the winter months dictate a wheat/fallow rotation. A fallow year is needed preceding dryland winter wheat production to conserve moisture and ensure economical yields for this region (see Young, 2002a; Young et al, 2002b; Nail et al., 2005). A typical farm in this region averages 5,000 acres (2,025 ha), of which half are cropped each year (Table 24.1). At the St. John site, an intermediate rainfall zone with 15" to 18" (381 to 457 mm) annual precipitation, a fallow year is needed to insure high-yielding winter wheat production but there is typically sufficient moisture to produce a spring grain following winter wheat (see Schillinger et al., 1999). The representative farm in this area averages 3500 acres (1418 ha), with two-thirds of the acreage (2345 acres or 950 ha) cropped each year (Table 24.1). At the Pullman site, averaging approximately 21 inches (533 mm) of precipitation annually, the typical farm size is 2500 acres (1012 ha), with all acres under cultivation each year. Thus, from 2345 to 2500 acres (950 to 1012 ha) are cropped each year in dryland areas. Finally, at Paterson, where crops are under irrigation, the representative farm is 1500 acres (608 ha), all of which are farmed each year. Further details, including typical machinery complements for each site by type of tillage, can be found in the appendices.

Table 24.1: Representative farm size, cropped acreage, precipitation, and yields for major crops by site

| Location | Representative farm size in acres (ha) | Precipi-tation inches (mm)/ year | Yields for major crops, units/ac (MT/ha) [2] | | | |
|---|---|---|---|---|---|---|
| | | | Winter wheat bu/ac (MT/ha) | Barley ton/ac (MT/ha) | Potato ton/ac (MT/ha) | Sweet Corn ton/ac (MT/ha) |
| Lind | 5,000 (2,025) | 10 (254) | 55 (3.69) | | | |
| St. John | 3,500 (1,418) | 17 (432) | 78 (5.24) | 1.5 (3.36) | | |
| Pullman | 2,500 (1,013) | 21 (533) | 100 (6.72) | 2 (4.48) | | |
| Paterson[1] | 1,500 (608) | 6 (152) | | | 33.5 (75) | 9.5 – 11[3] (21 – 25) |

[1] This site is under irrigation.

[2] MT = metric tons (1 MT = 1 Mg)

[3] Yields vary by year and tillage. See Appendices 24G and 24H for more detail.

Winter wheat is the dominant crop in the dryland region, as its long growing season can take advantage of winter precipitation. Average wheat yields vary greatly by year and across rainfall zones (Table 24.1). We use a high average value for winter wheat yields across all zones, representing well-managed farms and optimistic yield goals.

## Profitability by Region and Tillage Choice

Using the representative farms discussed above, profitability was determined for each region and tillage strategy with the following assumptions. Relevant crop prices were calculated from the average farmgate price received by Washington farmers for the five-year period 2004 through 2008; these prices are listed in Tables 24.2-24.5. Government farm program payments and crop insurance indemnities are excluded from this analysis, as we are focusing on a comparison of market returns. In another study in this region, the economic ranking of cropping systems did not change when government payments were included (Nail et al., 2007). Input prices were gathered from survey data for fall 2009 and are listed in detail in the appendices.

## Low Rainfall Cropping Region (under 15" ppt)

Lind represents the low rainfall cropping region, an area that has few alternatives other than winter wheat preceded by summer fallow. In this arid region, fertilizer is applied during the fallow year, typically in June. Thus, for the NT scenario, farmers in this region cannot apply fertilizer while planting as in higher rainfall regions. Yields were estimated to be 55 bu per acre (3.69 MT/ha), representing a well-managed farm with above average yields[1] for the region.[2] All of the dryland yield estimates in this study similarly represent well-managed farms for each region.

Two tillage scenarios were modeled: conventional tillage (CT), which used mechanical tillage for weed control and a double-disc drill, and no-till (NT), which used chemical weed control during the fallow year and a direct seed drill. Fertilizer was applied with an anhydrous applicator in June of the fallow year for both the NT and CT scenarios (see Appendix 24A).

Assuming equal yields for both systems, returns over total costs by rotation averaged $30 per acre ($74/ha) for CT and $17 per acre ($42 per ha) for NT (Table 24.2). The difference in profitability stemmed from higher herbicide costs in the NT system (Figure 24.1). The NT system used one Roundup® spray, an undercutter sweep operation, and one rodweeding during the fallow year, compared to one pass of a cultivator plus three rodweedings for the CT system during the same year. The NT system also had slightly higher seed costs as seeding rate is typically increased for no-till systems. Fuel usage was comparable between CT and NT. Given the relatively low revenue that occurs only every other year, keeping costs to a minimum is key to remaining profitable in this area.

Given the flexible nature of these models, sensitivity analysis is easily performed for different crop and input prices and yield scenarios. For example, if the price of Roundup® decreases by half (from $0.42/oz to $0.21/oz), then net returns for the NT system increase from $17/ac/yr ($42/ha/yr) to $20/ac/yr ($49/ha/yr). On the other hand, if the price for Roundup® doubles, then net returns for the NT system fall to $12/ac/yr ($30/ha/yr). These are fairly dramatic changes based on the price of one input, but this type of price fluctuation occurred in 2008, when the price for Roundup® more than doubled due to worldwide shortages.

Sensitivity on yields by system showed that if yield for the NT system is 10% less than for the CT system, net returns fall from $17/ac/yr ($42/ha/yr) to $8/ac/yr ($20/ha/yr). On the other hand, if the NT yield is 10% higher than for CT, net returns would increase to $26/ac/yr ($64/ha/yr), nearly comparable with the CT system at $30/ac/yr ($74/ha/yr). No till systems had 50% higher spring wheat yields in a recent Direct Seed Mentoring project, due to preservation of soil moisture in the spring (Painter et al., 2010). Thus, higher yields more than compensated for the increased costs of the reduced tillage system.

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[1] A five-year conservation study in this region produced wheat yields ranging from 27 to 77 bu per acre, with no yield differences observed between conservation and minimum tillage (Janosky et al., 2002)

[2] MT = metric tons (1 MT = 1 Mg); MMT = million metric tons (1 MMT = 1 Tg)

Table 24.2: Summary of Returns by Crop and Rotation for the Low Rainfall Cropping Zone ($/acre/year)

| | Unit | Yield (units/ac) | Price[1] ($/unit) | Revenue ($/acre) | *Annual Returns over Total Costs:* Conv. Tillage ($/acre) | Reduced Tillage ($/acre) |
|---|---|---|---|---|---|---|
| By Crop: | | | | | | |
| Winter Wheat (WW) | bu | 55 | $4.99 | $274 | $60 | $34 |
| Fallow (F) [2] | | | | $0 | | |
| By Rotation: | | | | | | |
| WW, F | | | | $137 | $30 | $17 |

[1]Prices are 5-year average prices received by Washington farmers from USDA-NASS, http://www.nass.usda.gov/

[2] Summer fallow costs plus appropriate interest costs are added to winter wheat costs.

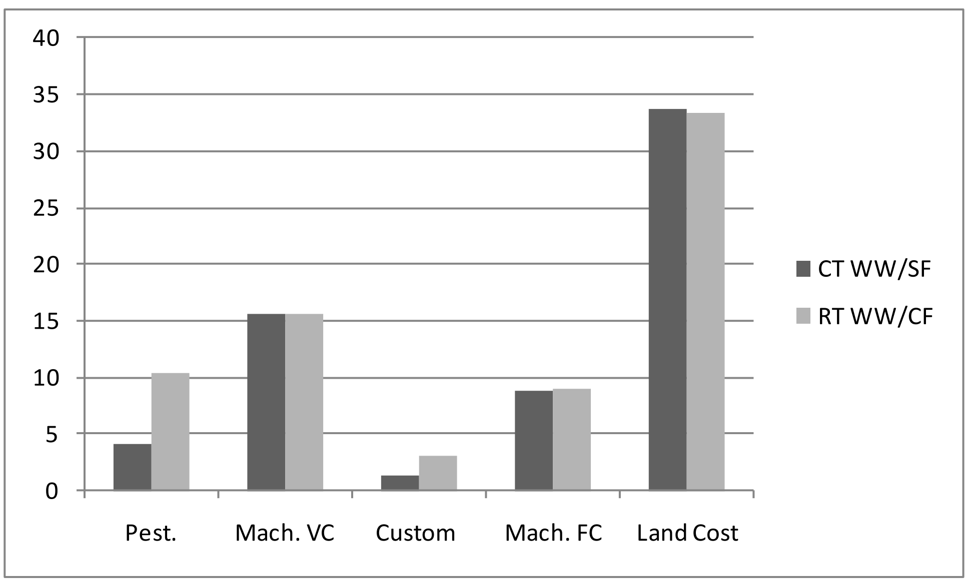



Figure 24.1. Selected production costs for the Lind site by tillage ($/acre/year)

Sensitivity analysis on crop prices changed the proportional difference in profitability between the two systems but not the absolute difference of about $12 per acre. Since yields are held constant, the profitability difference only reflects the difference in production costs. For example, if the price of wheat were $10 per bu, net returns would be $122/ac/yr ($301/ha/yr) for the CT scenario and $110/ac/yr ($272/ha/yr) for NT, a difference of about 10%, compared to 76% higher returns when wheat averages $5 per bu and rotational returns average $30 per acre ($74/ha) for CT and $17 per acre ($42 per ha) for NT. If NT can be shown to increase crop yields and thus make up this difference in profitability then profit-maximizing growers should be willing to make this investment in machinery and change their farming practices.

**Intermediate Cropping Region (15" to 18" ppt)**

The St. John site characterizes the region receiving 15 to 18 inches (381-457 mm) of annual rainfall. In this area, a winter wheat crop typically follows a fallow year, and a spring grain crop follows the winter wheat crop. Thus, land is cropped two years out of three. Winter wheat (WW) typically does quite well after a fallow year. Spring barley (SB) is used as the spring grain in this scenario. For our representative farm, we assumed identical yields under both tillage regimes of 78 bu/ac (5.24 MT/ha) for winter wheat and 1.5 ton/ac (3.36 MT/ha) for spring barley (Table 24.3). Rainfall can be limiting for spring crop production in this region, often resulting in a break-even or loss on this rotational crop, but in general it is economically and agronomically advantageous to follow this three-year rotation. Fallow land represents a cost without any revenue potential. The more land under cultivation, the more potential for profit, particularly if it is in wheat production, either winter or spring varieties. Also, decreasing the percentage of fallow land is preferred for erosion control.

In St. John, we modeled two tillage intensities: conventional tillage (CT) and no-till (NT). Under CT, summer fallow land was chiseled and cultivated in early spring, then fertilized with an anhydrous applicator in June (Appendix 24B). Four mechanical weeding operations took place over the course of the season. A double-disc drill was used to plant the winter wheat. Wheat stubble was plowed in the fall after harvest. CT spring barley land was cultivated, fertilized, and mechanically weeded in the spring before planting with a conventional double-disc drill. Barley stubble was left standing in the fall after harvest. Summer fallow operations included chiseling in March, cultivating and rodweeding in April, fertilizing in June, and rodweeding in June, July, and September. See Appendix 24B for more detail.

For the NT scenario at St. John, Roundup® was sprayed four times between spring barley harvest and planting of winter wheat (see Appendix 24C). No soil disturbance occurred except seeding with the no-till drill, which simultaneously applied fertilizer. Weeds were controlled with a 90' sprayer in fall and spring for winter wheat, and twice in the spring for spring barley.

Under these assumptions, NT was less profitable than CT, with average returns over total costs of $4 per acre ($10/ha) per year, compared to $19 per acre ($47/ha) per year for CT (Table 24.3). Since crop yields are equal across tillage scenarios under our assumptions, profitability differences stemmed from variations in production costs. Pesticide costs were more than double under RT, but machinery variable costs were higher (Figure 24.2). NT used 36% less fuel, and therefore also had slightly lower machinery costs, particularly for labor and repairs. However, these cost savings were outweighed by slightly higher seed and fertilizer costs and much higher herbicide costs. In terms of machinery complements for NT and CT, their value was nearly identical, but the types of machinery differed: the CT farm used a moldboard plow, a cultivator, a rodweeder, and a double-disc drill while the NT farm used a 90' sprayer, a mower, a wide harrow, and a direct seed drill. More details on the machinery complements and other details on crop production are available in appendices 24B and 24C.

Table 24.3: Summary of Returns by Crop and Rotation for the Intermediate Rainfall Cropping Zone ($/acre/year)

| | | | | | *Annual Returns over Total Costs:* | |
|---|---|---|---|---|---|---|
| | Unit | Yield (units/ acre) | Price[1] ($/unit) | Revenue ($/acre) | Conv. Tillage ($/acre) | No Tillage ($/acre) |
| By Crop: | | | | | | |
| Winter Wheat (WW) | bu | 78 | $4.99 | $389 | $59 | $36 |
| Spring Barley (SB) | ton | 1.5 | $126 | $189 | -$2 | -$24 |
| Fallow (F)[2] | | | $4.99 | $0 | -$111 | -$69 |
| By Rotation: | | | | | | |
| *WW, SB, F | | | | $193 | $19 | $4 |

[1]Prices are 5-year average prices received by Washington farmers from USDA-NASS, http://www.nass.usda.gov/

[2] Summer fallow costs plus appropriate interest costs are added to winter wheat costs.

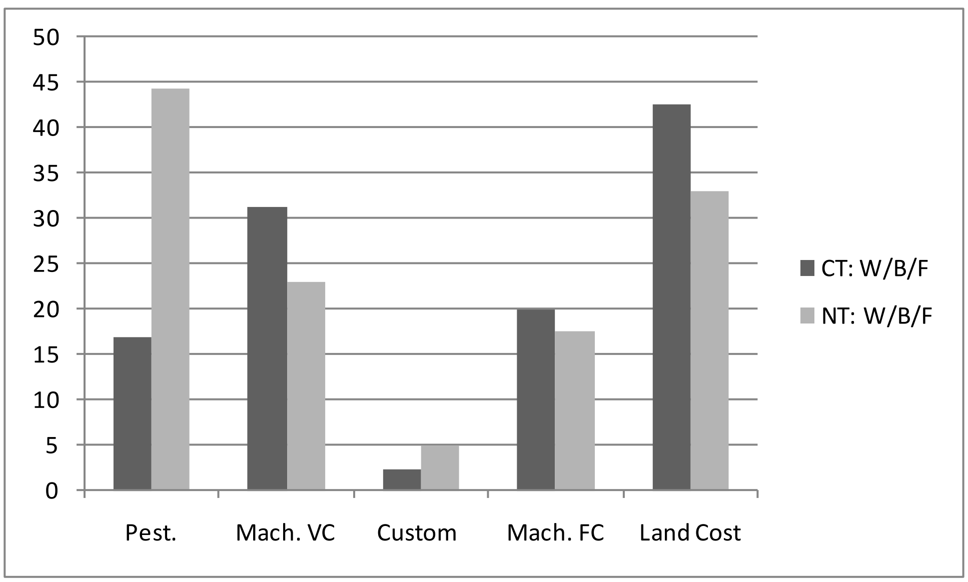



Figure 24.2. Select production costs for St. John site by rotation ($/acre/year).

Sensitivity analysis for various price assumptions showed that Roundup® price changes would also affect the relative profitability of NT for the St. John site. A 50% drop in price would increase the profitability of NT by $7/ac/yr ($17/ha/yr), which would then have net profits of $11/ac/yr ($27/ha/yr) compared to $19/ac/yr ($47/ha/yr) for CT. If Roundup® prices doubled, however, net returns for the NT scenario would be -$10/ac/yr (-$25/ha/yr), which is a non-sustainable return.

Yield sensitivity analysis for this region was performed assuming that yields under NT were either 10% higher or 10% lower than CT. If NT yields are 10% lower, this system had a net loss of $9/ac/yr (-$22/ha/yr). On the other hand, if NT yields are 10% higher, the two systems would be nearly comparable, with $17/ac/yr ($42/ha/yr) net returns for the NT system and $19/ac/yr ($47/ha/yr) for CT. This result is not implausible, as large yield increases have been achieved under NT in the ongoing Direct Seed Mentoring project, in which direct seed farmers plant land for conventional growers who are interested in no-till systems (Meyer, 2009; Painter et al., 2010).

**Annual Cropping Region (over 18" ppt)**

Pullman is located in the annual cropping region of the Palouse, characterized by 18 inches (457 mm) or more of annual precipitation. This highly productive dryland grain-producing region has relatively low adoption rates of no-till practices, approximately 8% of the farms in Whitman County (Conservation Tillage Information Center, 2008). Crop rotations are more varied in the annual cropping region, and we therefore examined two possible rotations for our representative farm: a very typical winter wheat-spring barley-peas rotation, and a less common but potentially more profitable and more soil conserving rotation of winter wheat-spring barley-soft white spring wheat. We assumed that crop yields did not vary by tillage (Table 24.4, below).

At the Pullman site we modeled three levels of tillage intensity for each rotation: conventional tillage (CT), reduced tillage (RT), and no-till (NT). Under CT, a regular double-disc drill was used for planting, and mechanical weeding was used throughout (see Appendix 24D). Winter wheat residue was plowed after harvest in the fall. Residues from other crops in the rotation were chiseled after harvest. Under RT, a regular double-disc drill was used for planting, and chemical weed control replaced mechanical weeding (see Appendix 24E). Seedbed preparation involved the use of a ripper shooter anhydrous fertilizer applicator prior to planting. All grain residues were chiseled after harvest, but pea residue was left standing. In the NT scenario, a no-till drill replaced the double-disc drill (Appendix 24F). Fertilizer was applied with the drill, eliminating the anhydrous applicator operation. Under NT, there was no soil disturbance except planting with a no-till drill.

A balance between costs for mechanical versus chemical weed control emerges for these dryland scenarios. In the more arid regions that have already been described, it is more economical to use mechanical weed control. In the more productive annual cropping region, pesticides substitute for a greater number of passes for mechanical weed control than in the drier areas, making herbicide use more cost effective. Herbicide costs for winter wheat production increased 55% for both reduced tillage scenarios, from $31/ac/year ($77/ha/yr) in the CT scenario to $48/ac/year ($119/ha/yr) for RT and CT. While pesticide usage increases as tillage intensity declines, these costs are outweighed in this region by reductions in machinery variable and fixed costs (Figures 24.3 and 24.4). Pesticide use is heavier in the pea rotation (Figure 24.4), yet decreased costs in other categories, including land costs, still outweighed the increase in pesticide usage for the reduced tillage scenarios. (Land costs decline as they are based on crop-share percentages; pesticide costs are typically included in the costs that are shared, while machinery costs are not shared.)

Fuel usage under RT and NT declines dramatically in this higher productivity area, which is tilled an average of six times per year under CT. Reduced tillage winter wheat production used one-third less fuel than conventional tillage winter wheat production, while no-till winter wheat production used 40% less. CT used 6 gal/ac (56 L/ac), compared to 4 gal/ac (37 L/ac) under RT and 3.6 gal/ac (34 L/ac) for NT. Other machinery usage costs such as repairs and machinery labor also declined relative to CT, falling 27% for RT and 31% for NT.

Fixed costs (those that occur regardless of cropping choice) such as machinery depreciation and interest on the machinery investment also differed depending on tillage intensity. CT had 25% higher fixed costs for machinery than either RT or NT simply because of its larger machinery complement. Although a more expensive drill was used in the NT scenario, no chisel, plow, cultivator, cultiweeder, or rodweeder was needed. Under the RT scenario, the less expensive double-disc drill was used, as well as a few other tillage implements. For further detail on machinery, see appendices 24D-24F.

Table 24.4: Summary of Returns by Crop and Rotation for the High Rainfall Annual Cropping Zone ($/acre/year)

| | | | | | *Annual Returns over Total Costs:* | | |
|---|---|---|---|---|---|---|---|
| | Unit | Yield (units/ acre) | Price[1] ($/unit) | Revenue ($/acre) | Conv. Tillage ($/acre) | Reduced Tillage ($/acre) | No Tillage ($/acre) |
| By Crop: | | | | | | | |
| Winter Wheat (WW) | bu | 100 | $4.99 | $499 | $129 | $133 | $135 |
| Spring Barley (SB) | ton | 2 | $126 | $252 | -$15 | -$8 | $3 |
| Soft White Spring Wheat (SWSW) | bu | 65 | $4.99 | $324 | $1 | $12 | $23 |
| Peas (P) | lb | 2000 | $0.10 | $196 | -$52 | -$44 | -$48 |
| By Rotation: | | | | | | | |
| WW, SB, SW | | | | $358 | $39 | $46 | $54 |
| WW, SW, P | | | | $340 | $32 | $34 | $37 |

[1]Prices are 5-year average prices received by Washington farmers from USDA-NASS, http://www.nass.usda.gov/

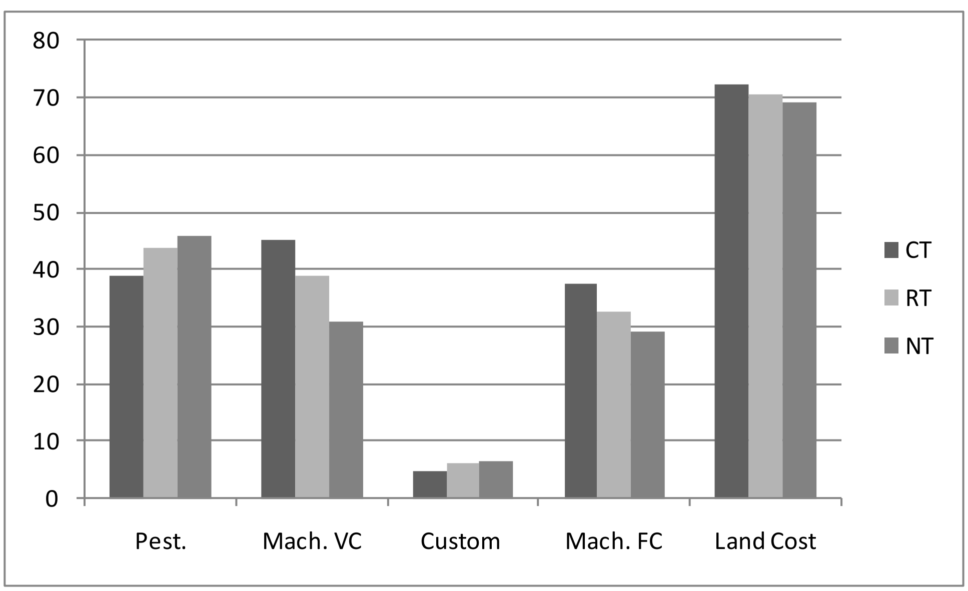



Figure 24.3. Selected variable costs by tillage for the winter wheat-spring barley-spring wheat rotation at Pullman ($/ac/yr)

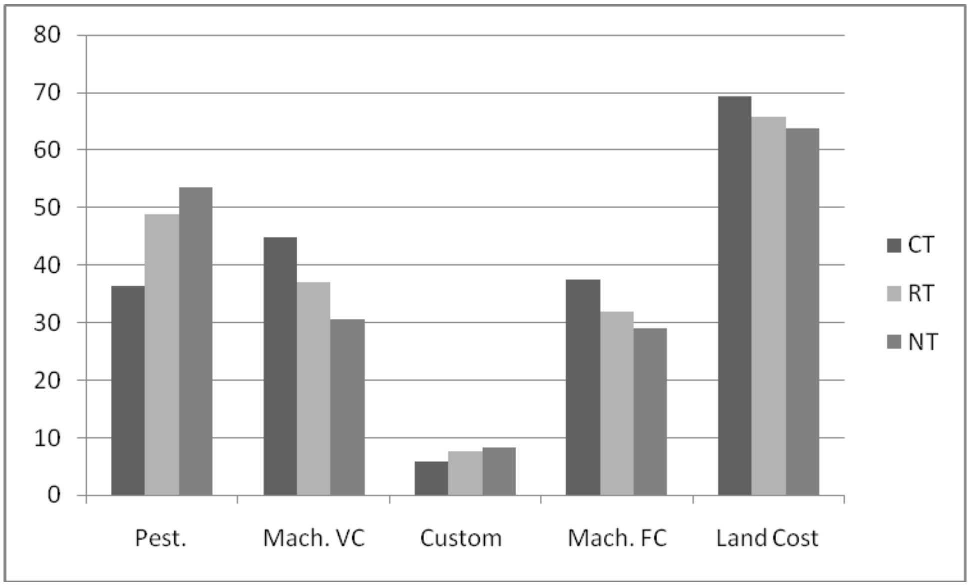



Figure 24.4. Selected variable costs by tillage for the winter wheat-spring barley-spring peas rotation at Pullman.

Assuming equal yields across tillage scenarios for all crops, net returns in Pullman for both rotations were slighter higher as tillage intensity declined. For the grain rotation (winter wheat-spring barley-spring wheat), net returns averaged $39/ac/year ($96/ha/yr) under CT, $46 ($114/ha) under RT, and $54 ($133/ha) under NT. The pea rotation was slightly less profitable overall, but profits followed the same pattern with tillage: $32/ac/year ($79/ha/yr) under CT, $34 ($84/ha) under RT, and $37 ($91/ha) under NT.

Sensitivity analysis was performed on Roundup® costs, yields, and fuel prices for this region. If the price of Roundup® falls by 50%, reduced tillage systems are relatively more profitable, with per acre average annual net returns by system increasing by $2, $4, and $6 ($5, $10, and $15 per ha) for CT, RT, and NT in the grain rotation, and $1, $3, and $6 ($2, $7, and $15 per ha) in the pea rotation. Alternatively, if the price of Roundup® doubles, the reduced tillage rotations are less profitable. In fact, the higher tillage systems are more profitable for the pea rotation under this scenario, with average annual net returns per acre of $29, $27, and $25 for CT, RT, and NT ($72, $67, and $62 per ha). The reduced tillage systems also lose their profitability advantage under the scenario of 10% yield reductions across all crops. Net returns for the NT systems fall to $30/ac/yr ($74/ha/yr) for the barley rotation and $13/ac/yr ($32/ha/yr) for the pea rotation, compared to average annual net returns of $39 and $32 per acre ($96 and $79 per ha) for the CT versions of these rotations. On the other hand, if NT yields increase by 10% over the CT yields, average annual net returns are $78 and $60 per acre ($193 and $148 per ha) for the barley and pea rotations, respectively, nearly double the returns under CT. One final analysis examines the impact of fuel price on relative profitability. If diesel price doubles, from $2.25 to $4.50 per gallon for off-road bulk diesel, the average annual per acre net returns by system are $24, $33, and $45 ($59, $82, and $111 per ha) for CT, RT, and NT in the barley rotation and $17, $22, and $28 ($42, $54, and $69 per ha) for CT, RT, and NT in the pea rotation. Thus, any number of changes in production costs, yields, and prices can easily change the relative profitability of these systems. A payment in the form of a carbon credit or subsidy for environmental services from no-till production could provide an additional incentive to change systems. Farmers are understandably risk averse, due to the inherent risk of agricultural production. Helping farmers move to more resilient systems, with reduced erosion and increased organic matter, would be a win-win situation. At this point, the majority of the farmers in this region are not convinced that no-till is a better system; we must work harder to extend the knowledge gained in numerous research trials.

Given these economic results, why is there not more adoption of NT in this area? At 8% for the county, no-till farming here is well below the national average (Conservation Tillage Information Center, 2008). There are several possible explanations for this. First, purchasing new machinery might cause severe cash flow problems, preventing producers from making the switch even though a reduced tillage cropping system would be more profitable. Selling the old machinery is a possibility, but salvage values for used machinery are typically quite low. Second, farmers may be hesitant to adopt no-till practices because of past failures observed in this region, before weed and disease issues as well as machinery problems were solved. The current generation of no-till drills (a combination drill and fertilizer applicator) is better than many of the earlier versions, but unfortunately needs to be pulled by an expensive, high horsepower tractor, thus further exacerbating potential cash flow problems. Third, producers may not believe that they can achieve equivalent yields with a no-till system. We will not address these yield issues in the current analysis, as sufficient evidence from dryland farmers in these regions shows equivalent or higher yields using current no-till technology and practices (see Guy and Lauvier, 2007; Janosky et al., 2002; Camara et al., 1999). However, these issues all need to be addressed in additional outreach programs for this area.

Another explanation for lower no-till adoption rates in this region is the underlying profitability of all these scenarios. Crop failures are virtually unknown in this higher rainfall area, unlike in the lower rainfall regions. Farmers may be resistant to change from something that has proven profitable. These rich, deep soils appeared to be endlessly fertile, but the region has lost about 40% of its topsoil from erosion over the years (Pimentel et al., 1995). This pervasive problem reduces the potential gains from technology (Walker and Young, 1986) and decreases the overall yields in this region (Busacca et al, 1985). If both on-site and off-site erosion damage are included, erosion damage is valued at approximately $5 per ton ($4.5/MT) (2008 dollars) for this region, based on Painter and Young (1994). Typical erosion rates for the CT pea rotation were 6.26 tons/acre/year

(14.02 MT/ha/yr), compared to 2.61 tons/acre/year (5.85 MT/ha/yr) for a no-till WW-WW-SW rotation, or a savings of 3.65 tons/acre/year (8.18 MT/ha/yr) (Painter et al., 1992). At $5 per ton ($5.51/MT), the public and private value of the soil savings as measured by off-site and on-site erosion would be $18.25 per acre ($45.08/ha), which would definitely shift the balance toward NT if this cost were added to the CT budget. These are very conservative erosion estimates compared to historical data that estimates an average of 24 tons/acre/year (54 MT/ha/yr) for seeded cereal crops during the 40-year period from 1939 to 1981 (personal records of Kaiser, in McCool and Busacca, 1999).

**Dryland Summary**

Overall, the higher rainfall annual cropping site in Pullman was the only dryland cropping location in which profits increased as tillage was reduced. This may be explained by the fact that the higher rainfall zone had more weed pressure, requiring more frequent tillage to control weeds. Consequently, more savings were realized when herbicides were substituted for mechanical control in this region. As technologies continue to develop for reduced tillage and no-till systems, they should become more cost-effective. For example, use of selective sprayers with infrared weed-seeking technology could reduce the amount of herbicide necessary, thus reducing costs of spraying in reduced tillage systems. Despite higher production costs for reduced tillage systems, growers are showing an increased interest in these systems as machinery improves and yield increases are seen in programs such as the very successful Direct Seed Mentoring Project (Painter et al., 2010). Finally, if total costs to society of both wind and soil erosion were added to actual production costs, the profitability of reduced tillage systems would increase relative to the conventional systems.

**Irrigated Region**

The Paterson site represents the irrigated cropping region in the Columbia Basin of central Washington. Two tillage regimes are modeled for this site: conventional tillage (CT) and reduced tillage (RT). We modeled the representative RT system on results obtained in the experimental RT irrigated crop rotation conducted as part of the Climate Friendly Farming™ Project, a three-year rotation of two years of sweet corn followed by one year of potatoes. Under reduced tillage, sweet corn yields declined by about 17% in year 2. CT corn had just a 5% yield decline in its second year.

In our modeled system, tillage was reduced in sweet corn by eliminating two passes of a Sunflower™chisel-chopper-packer that typically occur before planting. A no-till corn planter (12-row John Deere/Orthmann™) was used to seed directly into the soil without any pre-plant tillage. During potato production, the same two passes of the chisel-chopper-packer were eliminated, as well as post-planting rodweeding and dammer diker operations (see Collins et al., in review, and appendices 24G and 24H).

Reductions in the number of field operations represented just 2% to 3% of total costs for these crops, which are relatively expensive to produce. The net effect of reducing tillage, which decreased costs, and yield reductions, which decreased revenue, was a 1% decline in average returns over total costs for the RT scenario, from an average annual return of $809/ac/year ($1999/ha/yr) to $800/ac/year ($1977/ha/yr) (Table 24.5). With equivalent yields, the RT scenario would have been $31/ac/year ($77/ha/yr) more profitable than the CT scenario. Given that these modeling results are based on a three-year field trial, further research is needed to determine if it is feasible to reduce tillage and maintain competitive yields (Collins et al., in review). Given the widespread adoption of reduced tillage for planting corn in other areas of the country, and the success of NT corn planting for a large corporate farm in this region, it is likely that yield disadvantages from this study can be overcome. Other advantages of reduced tillage, including reduced wind and soil erosion, need to be considered as well. They could easily outweigh the economic impact of a small yield reduction (Lee, 1998; Papendick, 1998 and 2004). For example, blowing sand damages crops in this region; a reduced tillage field is compared to a conventionally tilled field at the Paterson site in the photos in Figure 24.5.

Table 24.5: Summary of Annual Returns by Crop and Average Annual Returns by Rotation for the Irrigated Cropping Zone ($/acre/year)

| | Conventional Tillage (CT) Yield (tons/acre) | Reduced Tillage (RT) Yield (tons/acre) | Price[1] ($/ton) | CT Returns over TC ($/acre) | RT Returns over TC ($/acre) |
|---|---|---|---|---|---|
| *By Crop:* | | | | | |
| Sweet Corn, Year 1 (SC1) | 11.00 | 11.00 | $78.66 | $27 | $46 |
| Sweet Corn, Year 2 (SC2) | 10.50 | 9.00 | $78.66 | -$12 | -$113 |
| Potatoes with cover crop (P) | 33.50 | 33.50 | $125.60 | $2,412 | $2,467 |
| *By Rotation:* | | | | | |
| SC1, SC2, P | | | | $809 | $800 |

Additional sensitivity analyses for this region showed promising results for the NT rotation. For example, if the price of diesel doubles from $2.25 to $4.50 per gallon, average annual net returns for CT and NT are $781 and $779 per acre, respectively ($1930 and $1925 per ha, respectively), which is a difference of about 0.25%. Given that diesel prices were approximately this high at some point during 2008, this is not an unlikely scenario. Likewise, if the price of labor increases, the relative profitability of the NT regime is affected less negatively than is the CT regime, which uses more labor for machinery operation than the NT scenario. For example, if machinery labor costs increase by 50%, average annual net returns fall to $789 per acre for the NT regime, a decline of $11 per acre (-$27 per ha), and they fall to $794 per for CT, a change of -$15 per acre (-$37 per ha).

**Modeling Profit-Maximizing Behavior in the Presence of Carbon Credits by Region**

Next, we examined the size of carbon credits sufficient to induce farmers to adopt reduced tillage or no-till systems, given the current profitability assumptions of these systems in our models. Assuming profit-maximizing behavior, how much would it cost to change farmer behavior? And what type of net gains would result, expressed in terms net carbon dioxide equivalents ($CO_2e$)?

We used a linear programming module called What's Best from the Lindo Corporation ([www.lindo.com](http://www.lindo.com)) to develop these models. This program is available as an add-on module for Excel. The beauty of these models is their flexibility; values in the model can be linked to other spreadsheets, which are in turn linked to data sets for input prices, crop prices, etc. For this reason, sensitivity analyses were easily performed for various price and yield scenarios.

We assume profit for the representative farm is maximized as follows:

Maximize $(P_{acre} + CC_{acre}) \times A_{RF}$

where $P_{acre}$ is equal to per acre net returns over total costs for the representative farm, $CC_{acre}$ is equal to the per acre carbon credit for switching to a reduced tillage system, and $A_{RF}$ represents the number of acres per representative farm. $CC_{acre}$ is calculated as the reduction in net $CO_2e$ emissions per acre multiplied by the designated dollars per metric ton for the carbon credit:

$$CC_{acre} = \left[ per\ acre\ reduction\ in\ CO2e\ emissions \times carbon\ credit\ \left(\frac{\$}{MT}\right)\right]$$

The only constraint in the model was a land constraint equal to the land available for that representative farm. These models are available upon request from the author.

Calculating metric tons of net carbon dioxide equivalent emissions sequestered per acre is inherently difficult. Variables including depth of measurement in the soil, time horizon, and whether or not to include residue layers on the surface are still being debated, as discussed elsewhere in this report. For this reason we calculated several carbon sequestration values for each scenario, and included an upper and lower bound to our estimates. In our discussion of results, we have focused on the values for the whole soil profile C (rather than 0–15 cm or 0–30 cm), including the residue layer on top of the soil, and we used a 12-year time frame. Upper and lower bounds for this set of values for each rotation and tillage option in each region are listed in Table 24.6. Further discussion on the merits of various measurements is provided elsewhere in this report.

Table 24.6: Net carbon dioxide emissions equivalent reduction for the whole soil profile, including residue layer, 12-year time frame, by site, crop rotation, and tillage (MT $CO_2e$ /acre/year)

| Site, rotation & tillage | Lower Bound | Upper Bound |
|---|---|---|
| Lind: RT WW-CF | 0.1140 | 0.1807 |
| St. John: NT WW-SB-CF | 0.1114 | 0.2485 |
| Pullman: RT WW-SB-SW | 0.0093 | 0.0308 |
| Pullman: NT WW-SB-SW | 0.1769 | 0.3334 |
| Pullman: RT WW-SB-SP | 0.0294 | 0.0398 |
| Pullman: NT WW-SB-SP | 0.1548 | 0.2763 |
| Paterson: RT P-C-C | 0.0717 | 0.1213 |

The values in Table 24.6 represent the upper and lower bounds of the net gain from changing to a reduced tillage system, and it is these values that determine the boundaries for per acre carbon credits. However, these net values do not account for the effect of nitrous oxide ($N_20$) emissions on net carbon dioxide emissions from each system. As noted elsewhere in this report, "although C was conserved by converting to RT or NT, when $N_2O$ emissions were considered, agriculture was likely still a source of $CO_2$ equivalents, rather than a sink." NT has the most potential to act as a sink, given its higher potential for reducing net carbon dioxide emissions. However, if we want to understand the full impact on GHG emissions, we must try to measure the total impacts of these changes. Lifecycle analysis (LCA) measurements that include net carbon dioxide emissions of fertilizer and fuel usage as well as the net carbon dioxide emissions in Table 24.6 are discussed elsewhere in this report as well. For this economic modeling effort, we are focusing only on tillage differences in net carbon dioxide emissions since the impact of tillage on $N_20$ emissions was determined to be either insignificant or not yet known with certainty.

**Results**

For the two dryland cropping regions with lower precipitation and the irrigated scenario, reduced tillage was less profitable than conventional tillage under the assumptions of our models. Carbon credits have the potential to increase profitability of the reduced tillage systems, but in regions such as these with low organic matter, gains in carbon sequestration tend to be quite small, as discussed elsewhere in this report. For Lind, using our more conservative lower bound estimation of carbon sequestration, the carbon credit would have to be $103 per metric ton net carbon equivalent (MT $CO_2e$) per acre ($254 MT $CO_2e$ per ha) in order to induce farmers to switch from conventional tillage to no-till, using the *whole soil profile, 12-year, with residue value* in Figure 24.6 below. The upper bound estimate using the same metric would require a carbon credit of $70 per MT $CO_2e$ ($173 MT $CO_2e$/ha) (Figure 24.7). Continuing to use the *whole soil profile, 12-year, with residue value* measurement, the carbon credit at the St. John site would need to be $102 per MT $CO_2e$ ($252 MT $CO_2e$/ha) for the lower bound estimate (Figure 24.6) and $62 per MT $CO_2e$ ($153 MT $CO_2e$/ha) for the upper bound estimate (Figure 24.7). When the estimate for carbon sequestration is increased, the incentive for switching to a lower tillage system can be lower, as more sequestration occurs for the same effort. At Paterson, the carbon credit would need to be $123 per MT $CO_2e$ ($304 MT $CO_2e$/ha) to induce growers to switch to the reduced tillage system for the lower bound estimate (Figure 24.6), and $67 per MT $CO_2e$ ($165 MT $CO_2e$/ha) for the upper bound estimate (Figure 24.7), using the same *soil profile, 12-year, with residue value* measurement.

Since the profitability difference between the conventional and the reduced tillage system at the Paterson site was just $8 per acre ($20/ha), it might seem that the carbon credit would not have to be very large to induce growers to switch to the reduced tillage system. However, the low-carbon soils at this site are not able to sequester much carbon, so it takes a very large carbon credit to make the two systems equally profitable. In reality, growers are likely to find the reduced tillage system appealing in order to reduce machinery costs and wind erosion, which can have severe yield impacts. The difference between the two systems represents just 1% of net returns over total costs, and thus would be considered inconsequential by many growers. As more trials are conducted on reduced tillage in irrigated systems, management techniques for reduced tillage should improve, and yield penalties should decline. In the initial three-year trial on which our analysis was based, sweet corn yields declined an average of 17% in the year two in the reduced tillage system, compared to a 5% drop in the conventional system (Collins et al., in review).

In our analysis of the annual cropping site at Pullman, reduced and no-tillage systems were more profitable under the assumptions of our models. However, offering a carbon credit to switch to lower tillage systems would serve as an incentive, and could potentially help overcome some of the barriers to adoption previously discussed. With a $10 per MT $CO_2e$ carbon credit per acre ($24.71 per MT $CO_2e$/ha), the 2,500-acre (1,012 ha) representative farm at this site using the barley rotation would receive a subsidy of $5,109 for switching from conventional tillage to no-till, using the *soil profile, 12-year, with residue* lower bound value in Figure 24.8 below. Figure 24.9 shows the impact of a $10 per MT $CO_2e$ carbon credit per acre using the upper bound estimate. The whole-farm subsidy for *C profile, 12-year, with residue* value for switching to no-till was just under $7,000 for the WW-SB-SP rotation, which is probably the most common rotation in this region, and $8,384 for switching to the NT version of the WW-SB-SW rotation.

Interestingly, the subsidy for switching from conventional to reduced tillage at the Pullman site with a $10 per MT $CO_2$e per acre carbon credit is quite small; this result is explained by the small gain in carbon sequestration between conventional and reduced tillage. Whole-farm subsidies for moving from CT to RT were all less than $1,000 per farm in Figures 24.8 and 24.9. It is unlikely that this level of subsidy would encourage any participation. Many farmers already use some form of RT in the higher rainfall region, as chem fallow is less expensive than summer fallow in areas with high weed pressure. In addition, its erosion benefits are quite visible.

For the Pullman site, carbon credits at any level result in benefits to growers. Assuming that the grower is profit-maximizing and thus will be using the WW-SW-SB rotation, Figures 24.10, 24.11, 24.12, and 24.13 show the impact of carbon credits ranging from $2 to $12 per MT $CO_2$e in $2 increments for the upper and lower bounds of net carbon dioxide equivalent measurements, including or excluding the residue layer. (The teal bar, which is the second from last in each grouping of 6 bars in the graph, measures sequestration for the soil profile, 12-year time frame.) Using this metric, $CO_2$e subsidies per farm ranged from $816 to $1667 at the $2 per MT $CO_2$e level, hardly enough to induce change or help purchase new equipment at the whole farm level. In contrast, at $12 per MT $CO_2$e, whole farm subsidies ranged from just under $5,000 in Figure 24.10 to $10,000 in Figure 24.13, from the lower to the upper bound, with and without including the residue layer. At these levels the incentives might begin to change behavior. Net farm income ranges from $65,000 to $115,000 per farm for the CT and RT rotations, so growers are relatively profitable without participating in a carbon program. However, since net farm income for the most profitable NT rotation is $135,000 per farm, there is a great deal of incentive to move toward NT in this area even without the carbon subsidy.

Given that carbon subsidies are calculated by multiplying per acre net $CO_2$e emission reductions by the subsidy level, the impact of changes in either factor are easily calculated. For example, if the carbon subsidy were $20 per MT $CO_2$e instead of $10, the impacts in Figures 24.8 and 24.9 would be double, ranging from $8,000 to $10,000 for the lower bound and $14,000 to nearly $17,000 for the upper bound. These levels would be much more likely to induce some changes. Likewise, as the estimates for reductions in net $CO_2$e emissions are refined, the impacts of those changes could easily be calculated.

## Conclusions

In areas where reduced tillage and no-till cropping are already more profitable than CT, subsidies may help farmers overcome other barriers to adoption, such as helping to purchase new equipment or buffer perceived risks of reduced yields from switching to no-till. However, in areas with very low capacity for sequestration, using carbon credits to encourage adoption of reduced tillage systems would not be cost effective, due to the high cost per metric ton $CO_2$e to induce changes. The gap in profitability between reduced and conventional tillage systems were relatively small, ranging from $15/ac in St. John to $13/ac/yr in Lind to $9/ac/yr in Paterson, so use of other incentives for switching to reduced tillage might be more cost effective than carbon credits.

There are additional benefits from switching to reduced tillage that are not captured in this analysis. Carbon emissions would decline, due to lower fuel usage; these benefits, which are relatively small, were not included in our calculation of net $CO_2$e impacts. More importantly for this erosion-prone region, switching to no-till reduces wind and soil erosion and creates benefits to society both off-site and on-site. In the U.S., off-site soil erosion damage has an estimated cost of $37.6 billion annually (Uri, 2001). On-site erosion damage impacts the future productivity of the land and thus its value. Wind erosion periodically wreaks havoc in this region with dust storms and regularly causes air quality concerns (Stetler and Saxton, 1996). A more comprehensive valuing of the benefits of no-till would no doubt make these reduced tillage systems more profitable.

Interestingly, a large corporate farm in the Columbia Basin has switched entirely to no-till; they lent their expensive no-till drill to our scientists for use in the Paterson trials. Given the extent of this farming operation, the high capital costs of the no-till equipment were easily spread over thousands of acres. Savings in fuel and labor costs as well as reducing the risk of crop loss and liability for blowing dust due to wind erosion were strong inducements to change.

In the lower rainfall area sites at Lind and St. John, carbon credits had to be very high to induce profit-maximizing farmers to switch to no-till systems. Even if we use the upper bound estimate for carbon sequestration, a carbon credit of $70 per MT CO2e would be necessary to induce a switch to no-till at Lind. In St. John, the carbon credit had to reach a value of $62 per MT CO2e to induce farmers to switch to NT. These levels of carbon credits are unlikely to occur in the near future. Technological improvements, including weed-seeking technology, would help reduce herbicide costs and improve the relative profitability of no-till systems in these arid areas. Finally, as in other sites, additional benefits both on and off the farm could be realized from reducing tillage, including improvements in soil quality, reductions in on- and off-farm soil erosion, and decreased wind erosion.

In all areas, including those where reduced tillage improves profitability, additional work may be needed to overcome current barriers to adoption. Farmers may need access to machinery, whether through low-interest loans or through programs like the Direct Seed Mentoring project currently underway by the Spokane Conservation District, University of Idaho, and WSU Extension (Meyer, 2009). This type of program, which has proven very successful for encouraging adoption of reduced tillage systems in the Midwest, addresses knowledge barriers and lowers risks associated with adopting new technologies. It pairs experienced NT and CT farmers to help CT farmers learn about no-till systems and then conducts a no-till trial on their farm. Typically, several hundred acres are seeded at no cost beyond materials for the CT farmer. Another successful program to reduce tillage in the low rainfall area involves cost-sharing for an undercutter purchase. This tillage implement can reduce overall tillage operations as it also applies fertilizer, and it generates more protective cover for erosion reduction (Young and Schafer, 2009).

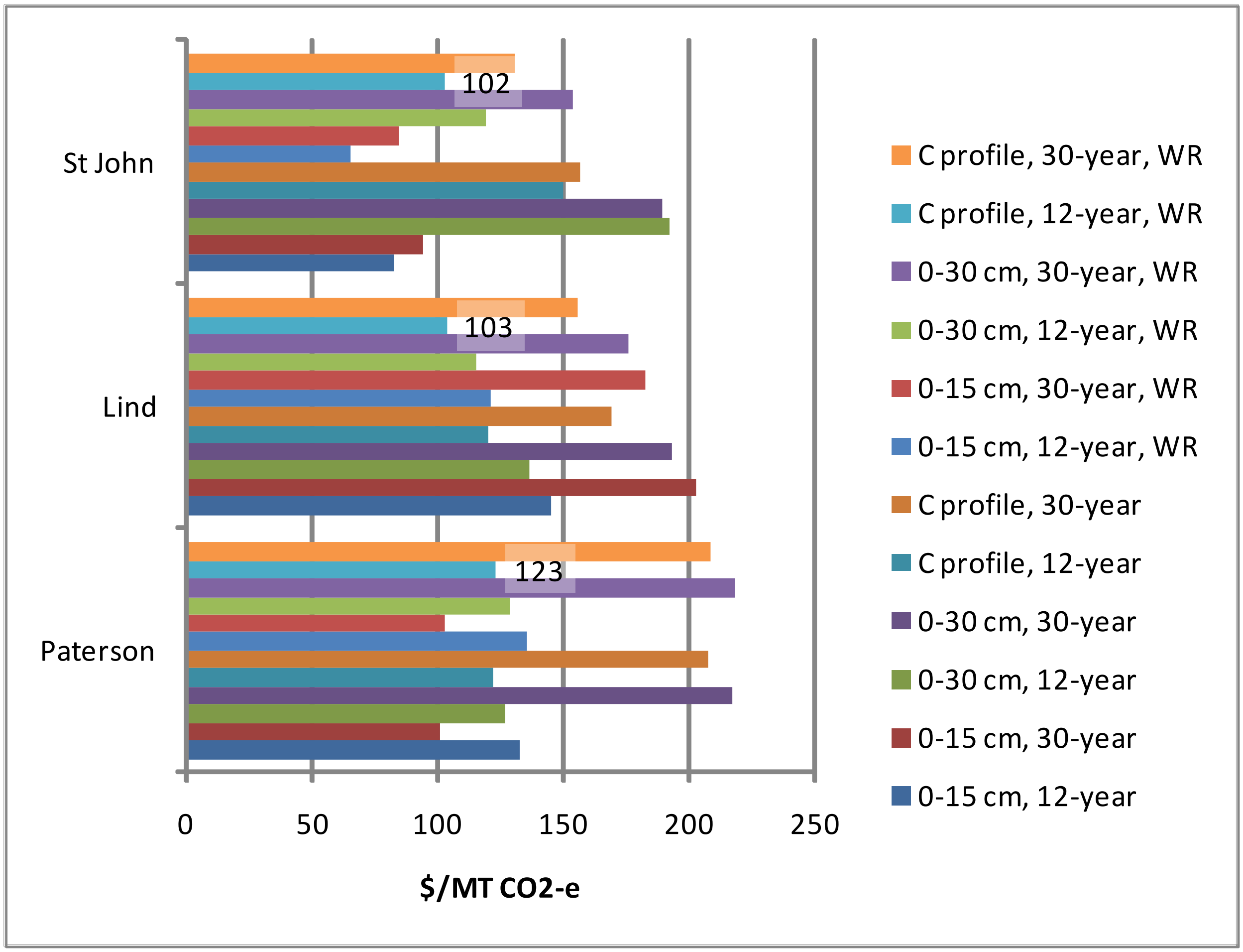
Surprisingly, shifting to a reduced tillage (RT) rotation does not make much difference in terms of net $CO_2e$ emissions – at a $10 per MT $CO_2e$ carbon credit, representative farms in the Palouse earned under $1,000 per farm for switching from conventional to reduced tillage. A shift from CT to RT does not reduce emissions nearly as much as a shift to NT; growers need to adopt the no-till system in order to qualify for the larger carbon credits. The RT rotation does decrease erosion significantly, and erosion itself impacts net CO2e emissions, particularly if fertilizers are being transported as well. Further research is needed to quantify these impacts.

The results of this economic analysis reflect a certain point in time in terms of crop and input prices, as well as our current ability to measure changes in $CO_2e$ emissions. Changes in crop prices and costs of farming will impact the net returns in these models, changing the farm's profitability as well as the potential of carbon subsidies to change behavior. Developing policies to encourage carbon sequestration may well focus on more general farm practices rather than specific measurements, due to the difficulty of measuring all benefits from reducing tillage in this productive yet fragile region.

Conventional Tillage

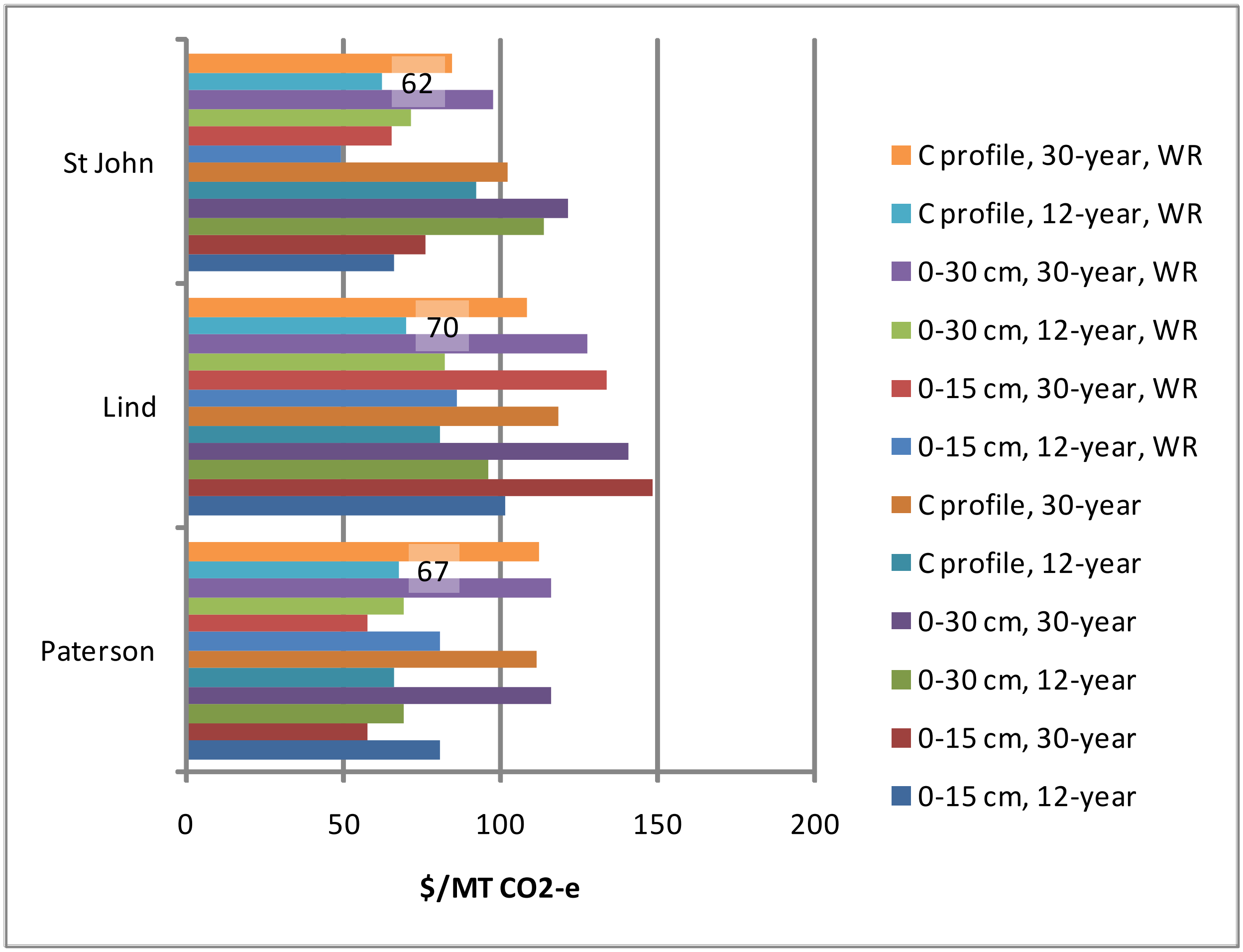
Reduced Tillage

Figure 24.5. Potato fields under conventional and reduced tillage, Paterson, WA.



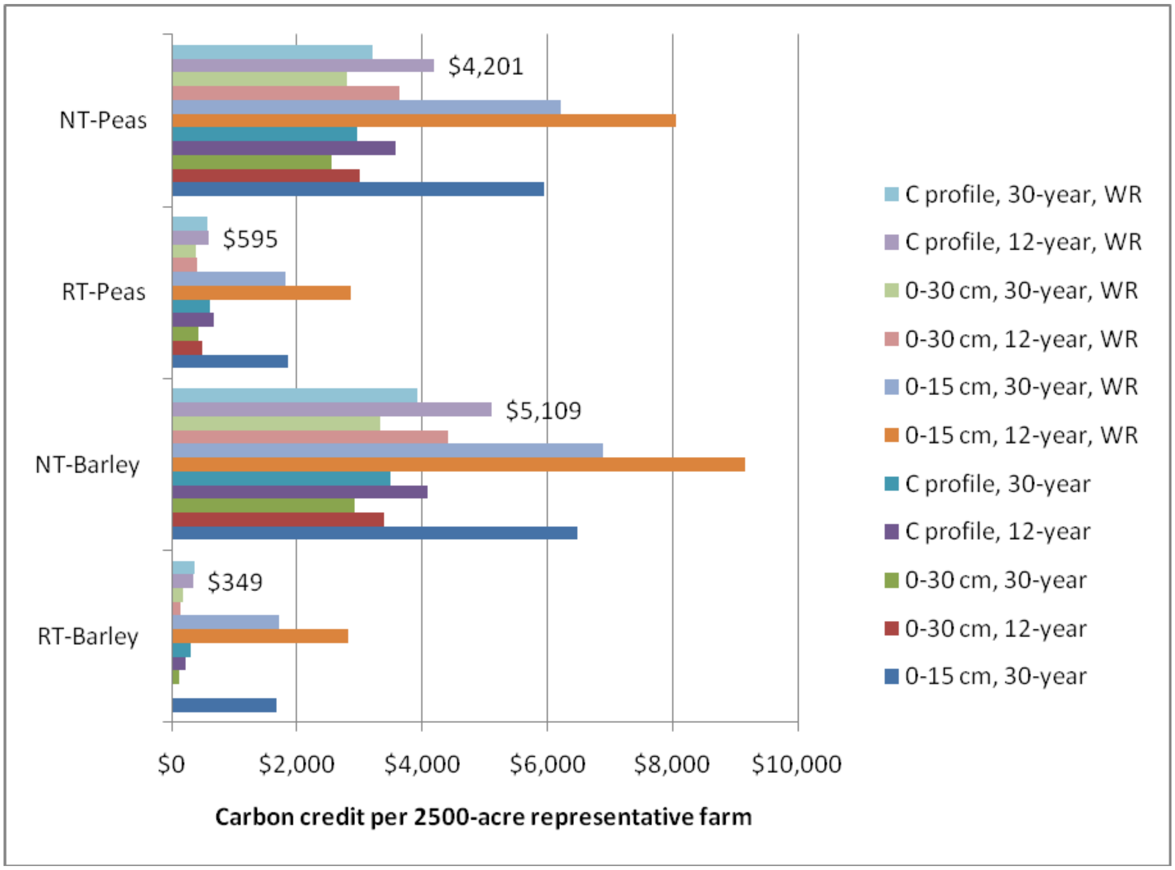

Legend: WR = with residue layer included in carbon sequestration estimates
MT = metric tons (1 MT = 1 Mg)

Figure 24.6. Minimum carbon credit values ($/MT $CO_2$e) needed to induce switch to NT by site, depth, time, and residue under lower bound carbon sequestration estimates.



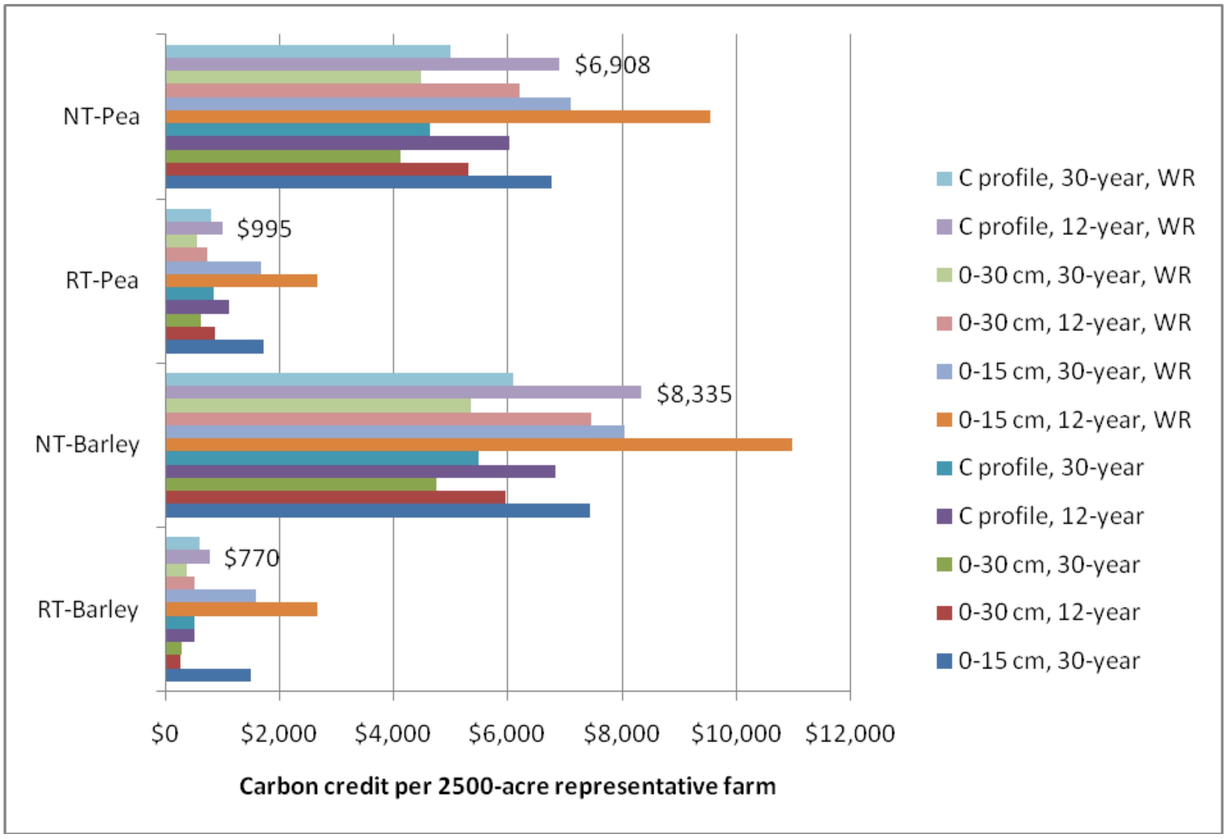

Legend: WR = with residue layer included in carbon sequestration estimates
MT = metric tons (1 MT = 1 Mg)

Figure 24.7. Minimum carbon credit values ($/MT $CO_2$e) needed to induce switch to NT by site, depth, time, and residue under upper bound carbon sequestration estimates.




Legend: WR = with residue layer included in carbon sequestration estimates
MT = metric tons (1 MT = 1 Mg)

Figure 24.8. Impact of a $10 per MT $CO_2$e carbon credit on whole farm carbon credits for Pullman site, by tillage reduction & rotation, lower bound estimate




Legend: WR = with residue layer included in carbon sequestration estimates
MT = metric tons (1 MT = 1 Mg)

Figure 24.9. Impact of a $10 per MT $CO_2$e carbon credit on whole farm carbon credits for Pullman site by tillage reduction & rotation, upper bound estimate

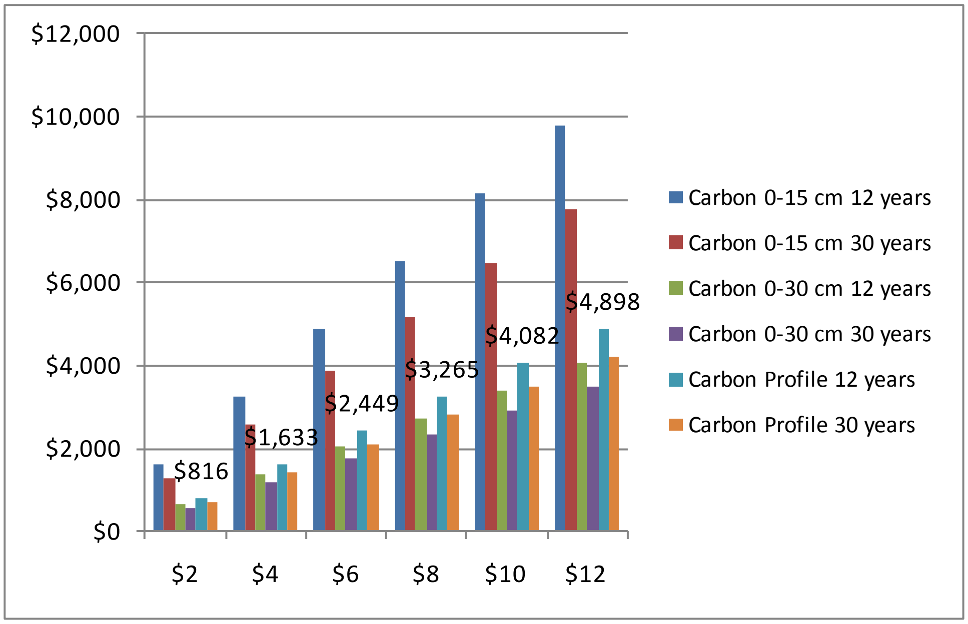



Figure 24.10: Carbon Credit by Depth, Time, and Price of Carbon ($/farm), Without Residue, Lower Bound, for the Profit-Maximizing no-till SW-WW-SB Rotation

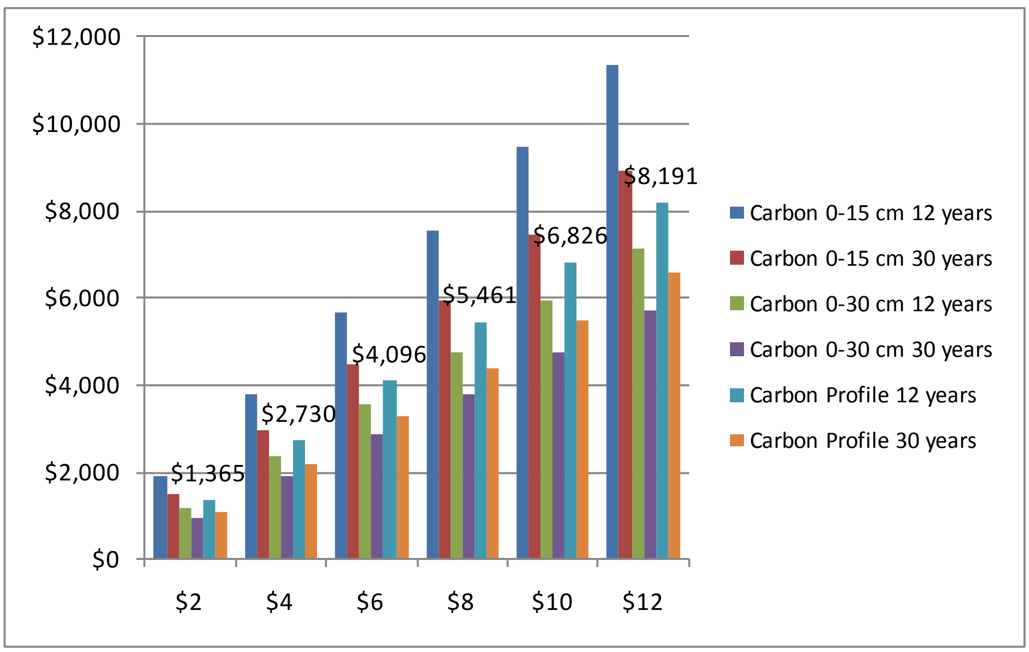



Figure 24.11: Carbon Credit by Depth, Time, and Price of Carbon ($/farm), Without Residue, Upper Bound, for the Profit-Maximizing no-till SW-WW-SB Rotation

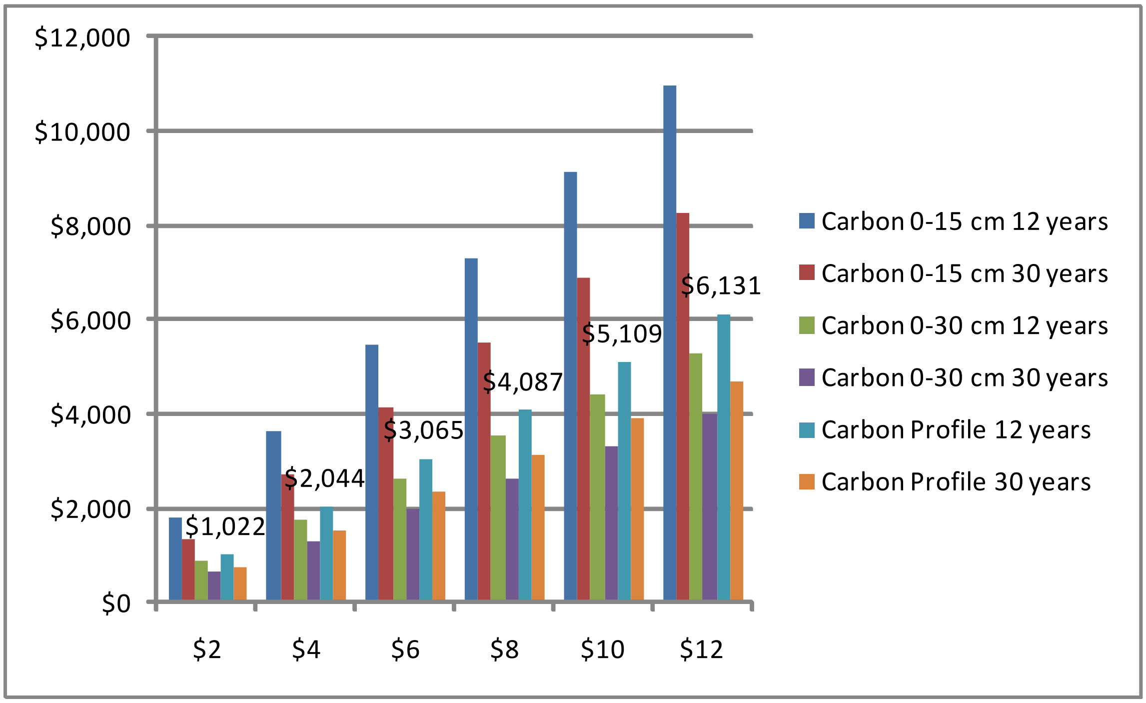



Figure 24.12: Carbon Credit by Depth, Time, and Price of Carbon ($/farm), With Residue, Lower Bound, for the Profit-Maximizing no-till SW-WW-SB Rotation

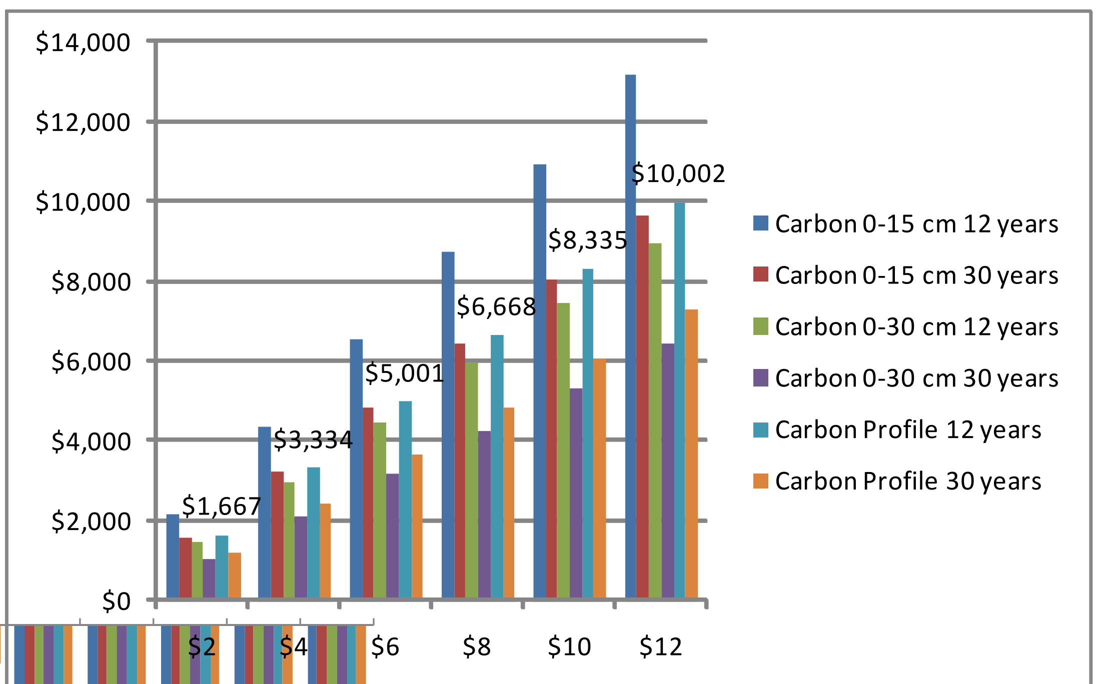



Figure 24.13: Whole Farm Carbon Credit in Pullman by Depth, Time, and Price of Carbon ($/farm), With Residue, Upper Bound, for the Profit-Maximizing no-till SW-WW-SB Rotation

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