Drainage water management impact on farm profitability

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Summary

The representative farm planning model that is used for the 2005 Purdue University Top Farmer Crop Workshop base case was extended to include managed drainage activities in order to evaluate the impact of drainage management time on farm operations. The analysis considered two alternative enterprises: rotation corn – soybeans with and without controlled drainage activities. The baseline solution assumed that controlled drainage has 10% higher average yields than free flowing drainage, one drainage control structure is needed each 20 acres, and all drainage management work was done on good field days. The results suggest that the baseline optimal solution was rotation corn-soybeans with controlled drainage where 1,500 acres were cultivated with corn following soybeans and 1,500 acres with soybeans following corn. Compared to the enterprise without controlled drainage, the annual returns to resources were 10% and 7.9% higher with and without EQIP subsidy respectively. Time opportunity cost for the managed drainage activities in each time period in the baseline solution was zero except for Dec. 6 – Apr. 21 period when its value was $10/hour and 108.69 hours of labor were hired. This was because of the controlled drainage activities (both installation and boards removal occur in this time period) that completely utilize full-time field labor and require additional hours of part-time labor to be hired. When hiring part-time labor was not available, the optimal enterprise was rotation corn-soybeans with managed drainage on 2/3 of the farm and corn-soybeans without controlled drainage on 1/3 of the farmland for a total annual contribution margin of $675,505. Increasing labor available by one more hour would increase the profits by $281.30 (Dec 6 – Apr. 21), $28.06 (Apr 22 – Apr 25), $338.18 (Apr. 26 – May 2), $229.48 (May 3 – May 9), $9 (May 10 – May 16), $28.07 (Nov. 1 – Nov 14 and Nov 15-Dec 5). In the baseline scenario the yield advantage threshold for profitability of managed drainage was 2.3% and 4.5% with and without EQIP subsidy respectively.

Keywords: corn, soybeans, drainage water management, farm planning model

JEL Classification: O21, Q12, J20

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Little is known about the economics of drainage management in general and almost nothing is known about the profitability of the practice in the Midwest. This analysis expands upon the previous research by including drainage water management activities into Purdue's Crop/Livestock Linear Program (PC-LP) used since 1968 in conjunction with the Purdue's Top Farmer Crop Workshop to quantify the impact of controlled drainage on farm operations and long-term profitability.

Subsurface tile drainage of cropland is a major source of the nitrate load to surface water in the Mississippi River Basin and has become a major concern in recent years, since nitrate has been shown to contribute to hypoxia and a severe reduction in fish populations in parts of the Gulf of Mexico. The Gulf of Mexico hypoxic zone is the second largest area of oxygen depleted waters in the world and appears to be growing (Rablais, Turner and Scavia 2002). Nitrate load, which constitutes the bulk of the total nitrogen load from the Mississippi River Basin to the Gulf of Mexico, has increased 300% since 1970 (Goolsby et al. 2001). Limiting drainage outflow in winter and midsummer can substantially reduce nitrate loss, and raising the water table in midsummer can potentially boost yields. Achieving the public goal of reduced nitrate in surface waters depend on nitrate management techniques such as drainage water management. Voluntary adoption of drainage water management by growers depends on the size of the yield increase and other private benefits while incentive programs require quantitative information on practice efficacy and on private benefits. The goal of this paper is to quantify the impact of drainage water management on farm operations and profitability. This will be achieved by extending the 2005 Purdue Top Farmer Crop farm-planning model, to include managed-drainage activities together with an economic budget that provides long-term profitability associated with the practice. This research will assist policy-makers in making decisions on drainage water management promotion and it will help growers faced with the choice of initiating controlled drainage on their land. The results will be used to make and disseminate recommendations on drainage water management according to the impact on profitability at the farm level.

Although nitrate loads to the Gulf of Mexico are a national concern, at a local level surface water nitrate concentrations have not been considered a major problem for most water uses in many parts of the Midwest. The problem is that too much nitrate-N load in surface waters from the Midwest drained agricultural land creates negative environmental impacts. Draft surface water nutrient criteria proposed for each EPA ecoregion may soon increase nitrate concerns at the local level. These draft criteria may be 75% lower than the current nitrate level in typical streams draining agricultural areas (Lemke and Baker 2002) so that many water bodies will likely fail to meet the nitrate criteria and will be listed as impaired, eventually requiring a Total Maximum Daily Loads (TMDL). Widespread implementation of Total Maximum Daily Loads (TMDL) for nitrogen will increase the local demand for agricultural management practices that have been demonstrated to substantially reduce nitrate loads to surface water.

Studies suggest that the principal source of nitrogen in the form of nitrate in the Mississippi River Basin is drained agricultural land in the Corn Belt (Burkhart and James 1999). Subsurface drainage is a common water management practice in agricultural regions with seasonal high water tables, which includes much of the Corn Belt. Such drainage has been found to increase losses of nitrate-N through the enhanced leaching of the soil profile (Gilliam, Baker and Reddy 1999). Subsurface drainage has become more controversial in recent years as the public becomes more knowledgeable about the negative environmental impacts.

Drainage water management systems have control structures that raise the effective height of the drain outlet during periods when field operations are not planned, usually winter and midsummer. This raises the water table level, reduces the amount of subsurface drainage from a field, and cuts the nitrate-N losses through drainage waters during those periods. The application of controlled drainage techniques is limited by topography. Highly steep or rolling terrain is generally not suited. The field should be level or have a constant slope that is less than 5% (Ministry of Agriculture and Food, British Columbia 1998). The process is economically unfeasible on land slopes greater than about 1% because more water control structures are needed as slopes increase (Busman and Sands 2002). Profitability is affected by the cost of the control structures, the labor required to manage drainage and the yield advantage of controlled drainage. Yields may be increased with controlled drainage because of greater water availability in the root zone during midsummer. Controlled drainage has been included as one of the best management practices for nutrient management in North Carolina for many years (Evans and Saggs 2004) and more limited data from Midwestern sites (Drury et al. 1996; Fausey et al. 2004) show the potential for large reductions in nitrate loads in this region as well. Because of the potential for improving water quality from drained lands, the technology has been named “conservation drainage” by some, drawing parallels with the dramatic change in tillage practice that has transformed many areas of corn and soybean production across the Midwest. Because the economics of drainage water management is not well understood and its impact on farm profitability is vital for widespread acceptance of environmentally beneficial practice, the overall goal of this study is to estimate the profitability of the practice given investment, time requirement and yield changes.

Literature review

Little is known about the economics of managed drainage in general and almost nothing is known about the profitability of the practice in the Midwest. There are a limited number of publicly available studies of the effect of drainage management on average crop yields and none for Midwestern conditions. Several studies have documented yield increases with sub-irrigation (Fisher et al. 1999; Drury et al. 1997; Sipp et al. 1986; Cooper et al. 1991 and 1992), but very few researchers have measured yield changes with managed drainage alone. For North Carolina coastal plain farmers, Evans and Skaggs (1996) indicate that managed drainage would increase potential yields by 10% to 20%, compared to conventional subsurface drainage. Trials by Tan et al. (1998) in Southwestern Ontario showed a slight soybean yield benefit for managed drainage under conventional tillage and a small yield decline with no-till, but neither of these yield differences was statistically significant at conventional levels. Nine out of 15 farmers involved in a central Illinois drainage management project said that they had higher yields with drainage management (Pitts 2003). All these studies use small plot or whole field data with the harvest from the combine transferred to a weigh wagon and weighed. Brown (2006) uses corn yield monitor data for 2005 on farm trials in Indiana and finds an average yield advantage with controlled drainage in the range of 1.4%-13%.

The Purdue Crop and Livestock Linear Progamming (PCLP) Model (Dobbins et al. 1994) and earlier versions have been used in a wide variety of research and extension efforts: choice of crop mix (Brink and McCarl 1978 and 1979), machinery selection for crops and farms (Danok , McCarl and White 1980), examining alternative cropping systems under resource constraints (Doering,1977), farm level feasibility of energy crops (Dobbins et al., 1990; Bender et al. 1984), economic and environmental implications of reintroducing forage rotations in the Midwest (Foltz, Martin and Lowenberg-DeBoer 1991) and adaptation of Corn Belt farms to climate change (Doering et al. 1997).

Methodology

An economic budget report is created in order to provide an estimate of the long-term profitability associated with the optimal plan. Managed drainage activities are developed for the PCLP Model in order to estimate the impact of drainage management time on farm operations. This is a well-validated model that has been used for over 7000 farmers to assess the impact of new technology on crop operation timeliness and profitability. For this analysis, the PCLP version used for 2005 Top Farmer Crop Workshop base case (Doster, Dobbins and Griffin 2005) is extended to include managed drainage activities. The objective of the representative farm model is to determine the combination of corn and soybeans that will maximize the returns above variable costs given the constraints on the scarce resources of land, labor and machinery. It is assumed that this analysis is done before controlled drainage is installed, so the cost of the drainage structure is considered variable in a partial budgeting sense. The cost of controlled drainage investment is detailed in the Appendix. The alternative solutions (recipes) considered were corn-soybeans rotation with drainage and corn-soybeans rotation without drainage.

The linear programming procedure follows a set of rules in deciding what and how much of the crop alternative to produce. The optimization algorithm looks at the available crop production recipes, picks the one that provides the greatest income and determines how many acres of each crop alternative to grow. It is assumed that controlled drainage activities are done using field labor (e.g. labor available on good field days).

A farm-planning model incorporating drainage management activities

In the baseline scenario the entire farm is assumed to be pattern tile drained and the choice is whether or not to manage that drainage by limiting outflow during certain periods. In many cases, drainage management activities (i.e. installation and removal of "boards") could be done on days when it is too wet for field activities, but there will always be some drainage management labor required on good field days. For example, some drainage management structures may be located in isolated parts of fields that are accessible by vehicles only on good field days. As a conservative assumption this analysis requires all drainage management to be done on good field days.

The case problem represents a 3000-acre farm with crop enterprises. A total of 20 different time periods was used to represent the production year. One-week periods were used during the critical spring planting period and two- or three-week periods were used during fall harvest. Thus, during the time periods when scheduling activities are most important, shorter period are used to give a more precise operational plan. The crop alternatives include: corn following soybeans and soybeans following corn.

It is assumed that crops are grown in specified combinations called rotations. The rotation included in the model is corn-soybeans with two production alternatives: corn-soybeans with controlled drainage and corn-soybeans without controlled drainage. Each alternative recipe is specific in terms of labor usage to control the drainage structure and the expected yield.

The labor force for the farm included 2 full-time workers working 12 hours per day and 3 part-time workers working up to 12 h per day. Part time labor could be hired at a wage rate of $10/hour as needed. The daily hours of usage for all machinery were assumed to be 20 hours for P&K Spreader and 12 hours for chisel, anhydrous, field cultivator, sprayer, planter and the drill.

Corn production was planted using the planter and the tillage system used a field cultivator. Fall application of phosphate and potash fertilizers was allowed (machine type: P&K spreader) as soon as the crop was harvested (any time between Nov. 15 - May 9). Spring tillage included broadcast application of herbicide (machinery type: sprayer, beginning three weeks after planting, to be completed within two weeks) and the application of anhydrous ammonia (machinery type: anhydrous, beginning four weeks after planting, to be completed within two weeks).

Soybeans were planted using the planter and the tillage system used a chisel plow (allowed period of operation: Nov. 1- Apr. 21) and field cultivator. Spring tillage included broadcast application of herbicide (machinery type: sprayer).

The yields for the best plant-harvest period for the corn-soybeans rotation without drainage were 160 bushels per acre for corn following soybeans and 53 bushels per acre for beans following corn (Purdue document #C-EC-7, p. 32-33). It was assumed that corn was dried and placed in storage. For the corn-soybean with drainage alternative it was assumed that the yields for the best plant-harvest period were 10% higher than the recipe without drainage (Lowenberg DeBoer, Moussa and Frankenberger 2004; Brown 2006). As more information becomes available on yield advantages of controlled drainage, management time requirements and other parameters of this analysis can be updated.

The penalties for late planting and moisture content at harvest were taken from the Purdue PC-LP Farm plan: B21-crop input form (C-EC-7). Storage of corn and soybeans were allowed. The price for corn was $2.50 per bushel at harvest prior to processing (e.g. drying) and $2.65per bushel after storage. The cost of off-farm processing will be incurred for corn sold at harvest prior to processing. The prices for soybeans were $6.00 per bushel at harvest prior to processing and $6.15 per bushel after storage.

Controlled drainage activities

For the corn-soybeans rotation without drainage management field drainage is assumed to be freeflowing. There is no labor time requirement to manage freeflowing drainage.

Controlled drainage activities and all crop operations in the model were performed using field labor that was available only on days suitable for fieldwork. The baseline analysis assumes that each drainage control structure affects 20 acres and it takes one hour to control (Lowenberg-DeBoer Moussa and Frankenberger 2004). For the corn-soybean rotation with “managed drainage” the activities are the following:

March - remove boards from structure to allow water table to drain to tile depth (in the model this can be done during Dec 6 – Apr. 21 time period).

June - five weeks after planting, reinsert boards to about 18-24 inches below soil surface, to save some drainage water that would otherwise be drained in growing season. Depth of the boards can be adjusted as needed for greater drainage for post-emergence pesticide or sidedress fertilizer applications (in the model this can be done 5 weeks after planting with a time frame of completion of 2 weeks).

September - about two weeks before planned harvest, remove boards in preparation for harvest and fall fieldwork (in the model this can be done 16 weeks after planting with a time frame of completion of 2 weeks).

December - after harvest and fall fieldwork, reinstall boards into control structure to allow water table to rise to about 6 inches from soil surface (in the model this can be done during Dec. 6- Apr. 21 time period.

Results

The PCLP analysis shows that the optimal enterprise is corn-soybeans rotation with controlled drainage, where 1,500 acres of corn-following soybeans and 1,500 acres of soybeans-following corn will be grown. The calendar of events and shadow prices by period are illustrated in table 1 and 2.

< Table 3 about here >

Table 3 shows that the annual return over variable costs (including investment in controlled drainage structures) for the optimal enterprise with EQIP payments is $689,108; this is $66,789 higher (10% increase) as compared to the alternative enterprise corn-soybeans rotation without drainage. Without EQIP Payments, the annual return to resources is $671,933; this is $49,614 higher (+7.9% increase) as compared to corn-soybeans rotation without drainage alternative.

Full-time field labor was completely utilized in the periods Dec. 6-Apr. 21, Apr. 26-May 2, May 3 – May 9, May 10-May16, Nov.1 – Nov. 14, Nov. 15-Dec. 5. Additional part-time labor was hired only for the periods Dec. 6-Apr.21, Apr. 26-May 2, May 3 – May 9, Nov.1-Nov14 and the additional revenue obtained when the available field labor would increase by one hour was $10. For the enterprise without managed drainage full-time field labor was also fully utilized in the periods Nov 1-Nov 14 and Nov 15 – Dec 5 but no additional part-time labor was hired. For the enterprise with controlled drainage the additionally 1.25 hours of part-time labor hired were due to soybean harvesting and chiseling operations on additionally 40 acres of land as opposed to the enterprise without controlled drainage. Table 4 shows that the opportunity cost of time devoted to drainage management is zero for all time periods of the model except for the Dec. 6 – Apr. 21

when its value was $10 per hour for a total of $1086.90 per farm. This is due to the controlled drainage activities, as both installation and boards' removal occur during Dec.6-Apr. 21. The analysis does not require additional labor for the midsummer installation and removal boards in the control structures. This is because with chemical weed control in corn and soybeans, full time farm workers have enough time to handle drainage management while completing other tasks. With mechanical weed control or crops that require more summer labor (e.g. forages, vegetables), controlled drainage may create summer labor bottlenecks.

< Table 4 about here >

Break-even yield advantage was estimated in order to reflect the lowest yield increase needed for the controlled drainage enterprise to come into the solution. With EQIP subsidy this was 2.3% and without subsidy 4.5%. Thus, with the subsidy, if yield advantage caused by controlled drainage is below 2.3% (4.5% without subsidy), controlled drainage drops out of the solution and is profitable to choose free flowing whole farm field drainage.

To reflect the impact of extending the time period when the boards are controlled, boards installation and removal was allowed in the model any time between the periods of Dec 6 – April 25. The optimal solution was corn-soybeans rotation with controlled drainage and the annual profit increased with $133 since additional part-time hired labor decreased with 13.38 hours. Full-time field labor was completely utilized in the periods

Dec. 6-Apr. 21, Apr 22-Apr 25, Apr. 26-May 2, May 3 – May 9, May 10-May16, Nov.1 – Nov. 14, Nov. 15-Dec. 5. Additional part-time labor was hired only for the periods Dec. 6-Apr.21, Apr. 26-May 2, May 3 – May 9, Nov.1-Nov14 and the additional revenue obtained when the available field labor would increase by one hour was $10. Table 5 shows the opportunity cost of time devoted to drainage management is zero for all time periods of the model except for the Dec. 6 – Apr. 21 when its value is $10/hour, for a total of $953.10 for the farm. This is less than with the baseline scenario since 13.37 h of managed drainage are performed during Apr 22- Apr 25 with full-time field labor instead of being performed during Dec 6-Apr 21.

< Table 5 about here >

When board installation after harvest and fieldwork was allowed earlier, to be performed any time Nov 1 – Apr. 21, the optimal solution remained corn-soybeans rotation with controlled drainage and the annual profit stayed the same as with the baseline scenario. Board installation was performed during Nov 1-Dec 5 time period as opposed to Dec 6-Apr21 with the baseline scenario.

Full-time field labor was completely utilized in the periods Dec. 6-Apr. 21, Apr. 26-May 2, May 3 – May 9, May 10-May16, Nov.1 – Nov. 14, Nov. 15-Dec. 5. Additional part-time labor was hired only for the periods Apr. 26-May 2, May 3 – May 9, Nov.1-Nov14 and the additional revenue obtained when the available field labor would increase by one hour was $10. Table 6 shows that the opportunity cost of time devoted to drainage management is zero for all time periods of the model except for the Dec. 6 – Apr. 21 when its value is $10/hour, for a total of $1099.30 for the farm.

< Table 6 about here >

Sensitivity analysis

Prices, yields and other parameters of the model may vary, so it is important to test the sensitivity of the analysis to these parameters. Given the recent increases in fuel and nitrogen fertilizer prices it is particularly important to test sensitivity with respect to them.

< Table 7 about here >

Sensitivity to N prices

Table 7 shows that when 10% increase in nitrogen price was considered (Miller 2005) the optimal enterprise remained corn-soybeans rotation with controlled drainage where 1,500 acres of corn-following soybeans and 1,500 acres of soybeans-following corn will be grown, but annual returns to resources were $6,705 lower (with EQIP subsidy this represents 0.97% decrease and 0.99% decrease without subsidy) than the optimal enterprise in the baseline scenario. The results regarding opportunity cost of drainage management and the availability of field labor stayed the same as in the original problem. Compared to the enterprise without controlled drainage, the annual return to resources for the optimal enterprise is 10.7% and 7.9% higher with and without EQIP payments respectively.

Sensitivity to fuel prices

Table 7 shows that when fuel prices was assumed to increase by 55% (EIA), the optimal enterprise remained corn-soybeans rotation with controlled drainage where 1,500 acres of corn-following soybeans and 1,500 acres of soybeans-following corn will be grown, but annual returns to resources were $14,850 lower (with EQIP subsidy this represents 2.1% decrease and 2.2% decrease without subsidy) than the optimal enterprise in the baseline scenario. The results regarding opportunity cost of drainage management and the availability of field labor stayed the same as in the original problem. Compared to the enterprise without controlled drainage, the annual return to resources for the optimal enterprise is 10.9% and 8.1% higher with and without EQIP payments

Since the application of managed-drainage is controlled by topography (on land with more slope more water control structures are needed as slopes increase), two additional scenarios were included:

1. One structure controls 10 acres;
2. One structure controls 5 acres.

<Table 8 about here >

Table 8 shows that when one structure was assumed to control 10 acres, the optimal enterprise was rotation corn-soybeans with managed drainage on 1913.2 acres and corn-soybeans without controlled drainage on 1086.9 acres for a total annual contribution margin of $675,907. Compared to corn-soybeans rotation without controlled drainage, the annual return to resources for the optimal enterprise was 3.24% higher and 2.24% lower with and without subsidy respectively. Additional labor was hired in the periods Dec 6 – Apr. 21, Apr 26 – May 2, May 3 – May 9 and no labor bottleneck occurred in June and July.

Table 8 shows that when one structure was assumed to control 5 acres, the optimal enterprise was rotation corn-soybeans with managed drainage on 956.6 acres and corn-soybeans without controlled drainage on 2043.4 acres for a total annual contribution margin of $648,416. Compared to corn-soybeans rotation without controlled drainage, the annual return to resources for the optimal enterprise was 6.6% and 17.5% lower with and without subsidy respectively than the enterprise without controlled drainage. Additional labor was hired in the periods Dec 6 – Apr. 21, Apr 26 – May 2, May 3 – May 9, and no labor bottleneck occurred in June and July. Therefore, when land is more sloped and one drainage structure controls either 10 or 5 acres, it is more profitable to allow free flowing whole farm field drainage except for the case with subsidy payments and one drainage structure controlling 10 acres when it is more profitable to control drainage on 2/3 of the farm.

When hiring part-time labor was not allowed, the optimal enterprise was rotation corn-soybeans with managed drainage on 1913.2 acres and corn-soybeans without controlled drainage on 1086.9 acres for a total annual contribution margin of $675,505. The available full-time labor was completely utilized in the periods of Dec. 6 – Apr. 21, Apr. 22-Apr 25, Apr. 26-May 2, May 3-May 9, May 10 – May 16, Nov. 1 – 14, Nov. 15-Dec. 5. Increasing its amount by one more hour would increase the profits by $281.30 (Dec6 – Apr. 21), $28.06 (Apr 22 – Apr 25), $338.18 (Apr. 26 – May 2), $229.48 (May 3 – May 9), $9 (May 10 – May 16), $28.07 (Nov. 1 – Nov 14 and Nov 15-Dec 5). Thus, increasing the number of hours worked by the full-time labor available on the farm has a high value, as there are substantial profits associated with working one more hour.

Conclusions

When two alternative enterprises were considered (rotation corn-soybeans with and without managed drainage) under baseline assumptions, the PCLP model analysis showed that the managed drainage activities came into the optimal solution. The baseline conditions are that the whole farm is pattern tile drained, all drainage management work must be done on good field days and managed drainage results in 10% higher corn and soybean yields. The optimal solution under baseline conditions was corn-soybeans rotation with controlled drainage with 1,500 acres of corn following soybeans and 1,500 acres of soybeans following corn. Compared to the enterprise without controlled drainage, the annual returns were 10% and 7.9% higher with and without EQIP subsidy respectively.

Time opportunity cost for the managed drainage activities in each time period was zero except for Dec. 6 – Apr. 21 period when its value was $10 per hour or a total of

1086.90 per farm. This was because of the controlled drainage activities (both installation and boards removal occur in this time period) that completely utilize full-time field labor and require 108.69 additional hours of part-time labor to be hired.

When hiring part-time labor was not available, the optimal enterprise was rotation corn-soybeans with controlled drainage on 1913.2 acres and corn-soybeans without controlled drainage on 1086.9 acres for a total annual contribution margin of $675,505. The available full-time labor was completely utilized in the periods of Dec. 6 – Apr. 21, Apr. 22-Apr 25, Apr. 26-May 2, May 3-May 9, May 10 – May 16, Nov. 1 – 14, Nov. 15-Dec. 5. Increasing its amount by one more hour would increase the profits by $281.30 (Dec6 – Apr. 21), $28.06 (Apr 22 – Apr 25), $338.18 (Apr. 26 – May 2), $229.48 (May 3 – May 9), $9 (May 10 – May 16), $28.07 (Nov. 1 – Nov 14 and Nov 15-Dec 5).

Sensitivity of corn-soybeans rotation with controlled drainage plan was carried with respect to fuel and nitrogen price increase. The optimal solution remained corn-soybeans rotation with controlled drainage. With 10% higher nitrogen prices the annual returns decreased by 0.97% and 0.99% with and without EQIP subsidy respectively. With 55% higher fuel prices the annual returns decreased by 2.1% and 2.2% with and without subsidy respectively.

Compared to corn-soybeans rotation without drainage, with 10% higher nitrogen price the annual return to resources for the optimal enterprise is 10.7% and 7.9% higher with and without EQIP payments respectively; with 55% higher fuel price, the annual return to resources for the optimal enterprise is 10.9% and 8.1% higher with and without EQIP payments respectively.

When the land is more sloped and one drainage structure controls 10 acres or less a 10% yield increase is not enough to compensate for the cost of the control structures and the additional labor, except for the case with subsidy payments and one drainage structure controlling 10 acres when it is more profitable to control drainage on 2/3 of the farm. If control structures were installed without cost to the landowner (e.g. by the government for environmental reasons) the benefits at a 10% yield increase would cover the added labor cost. With the subsidy, if yield advantage due to controlled drainage is below 2.3% (4.5% without subsidy), controlled drainage drops out of the solution and is more profitable to choose free flowing whole farm field drainage.

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Appendix

In computing the annual cost of the drainage structure for the whole field, it was assumed that the cost of purchase and installation of one structure is $1,500 (NRCS, code 587), the useful life of the drainage structures is 20 years and that the cost of capital is 10%. Since one structure controls 20 acres (Lowenberg DeBoer, J. et al.) a 3,000 acre field needs 150 structures. So the total cost of drainage structures is 150*$1,500=$225,000. To compute the annual cost on controlled drainage structures, incentive payments from NRCS were subtracted (code 554 Drainage water management: incentive payment of $40 per managed acre up to 50 acres for a total of $2,000 and code 587 Structure for Water Control: subsidy payment of 50% of the average cost to purchase and install the control structures = $225000/2=$112500). The total cost of drainage the farmer has to pay is 225,000-112500-2000=$110500. Using straight line depreciation and an interest charge on the initial investment, the annual cost for the field is:

- With EQIP subsidy 16,575 = 110,500/20 +110,500*0.1
- Without EQIP subsidy 33,750 = 225,000/20 +225,000*0.1

Annual cost of drainage with the assumption that 1 structure controls 10 acres:

Total structures needed=3000/10 = 300. Total cost of structures = 300*1,500 = $450,000

Total cost for the farmer with subsidy = 450,000 – 2000 – 225,000 = $223,000

Annual cost for the field is

- With EQIP subsidy 33,450 = 223000/20 +223000*0.1
- Without EQIP subsidy 67,500 = 450,000/20 +450,000*0.1

Annual cost of drainage with the assumption that 1 structure controls 5 acres:

Total structures needed=3000/5 = 600. Total cost of structures = 600*1,500 = $900,000

Total cost for the farmer with subsidy = 900,000 – 2000 – 450,000 = $448,000

Annual cost for the field is

- With EQIP subsidy 67200 = 448000/20 +448000*0.1
- Without EQIP subsidy 135000 = 900,000/20 +900,000*0.1

Annual cost of drainage with the assumption that 1 structure controls 20 acres and no additional labor hiring was allowed:

Total structures needed=1913.2/20= 96.Total cost of structures = 96*1,500 = $144000

Total cost for the farmer with subsidy = 144000 – 2000 – 72,000 = $70,000

Annual cost for the field is

- With EQIP subsidy 10,500 = 70000/20 +70000*0.1
- Without EQIP subsidy 21,600 = 144000/20 +144,000*0.1

Table 1. Crop Activities by Period-Calendar of Events and Shadow Prices for Corn-Soybeans Rotation with Controlled Drainage

Period	Good field days	Crop	Operation	Acres	Shadow prices: Big tractors ($/h)	Shadow prices: Planters ($/h)	Shadow prices: Combine ($/h)	Shadow prices: Dryer ($/pont)	Shadow prices: Field labor ($/h)	Drainage mgmt time (h)
Dec. 6-Apr. 21	9.3	Corn	drainage	1500					10	300
		Corn	drainage	1500						
		Beans	drainage	1500						
		Beans	drainage	1500						
Apr. 22-Apr 25	1.3	Corn	field cult	4.79	1167.82					
		Beans	field cult	400.4						
Apr. 26-May 2	2.4	Corn	field cult	748.05	1157.81	312.73			10	
		Corn	planter	752.84						

Table 1. Crop Activities by Period-Calendar of Events and Shadow Prices for Corn-Soybeans Rotation with Controlled Drainage (Continued)

Period	Good field days	Crop	Operation	Acres	Shadow prices: Big tractors ($/h)	Planters ($/h)	Combine ($/h)	Dryer ($/pont)	Field labor ($/h)	Drainage mgmt time (h)
May 3 - May 9	2.4	Bcorn	field cult	614.69	1157.81	166.83			10	
		Corn	planter	614.69						
		Beans	field cult	133.36						
		Beans	planter	138.15						
May10-May16	3.1	Beans	field cult	966.23	1158.8				9	
		Beans	planter	810.52						
May17-May23	3.1	Corn	field cult	132.47						
		Corn	planter	132.47						
		Corn	post-planting	689.8						
		Beans	planter	551.33						

Table 1. Crop Activities by Period-Calendar of Events and Shadow Prices for Corn-Soybeans Rotation with Controlled Drainage (Continued)

Period	Good field days	Crop	Operation	Acres	Shadow prices					
					Big tractors ($/h)	Planters ($/h)	Combine ($/h)	Dryer ($/pont)	Field labor ($/h)	Drainage mgmt time (h)
May24-May30	3.8	Corn	post-planting	63						0
		Beans	post-planting	138.2						
May 31-Jun 6	3.8	Corn	post-planting	614.7						34.49
Jun 7 - Jun 13	3.5	Beans	post-planting	810.5						10.06
		Beans	post-planting	460.6						
Jun 14 - Jun 20	3.5	Corn	post-planting	132.5						30.73
		Beans	post-planting	90.7						
Jun 21 - Jun 27	3.5	Corn, Beans	drainage	1271.2						63.56
Jun 28 - Jul 4	3.5	Corn,Beans	drainage	232						11.16
Jul 5 - Jul 11	3.5	Corn, Beans	drainage	0						0
Jul 12-Aug. 29	29	Corn, Beans	drainage	891						44.55

Table 1. Crop Activities by Period-Calendar of Events and Shadow Prices for Corn-Soybeans Rotation with Controlled Drainage (Continued)

Period	Good field days	Crop	Operation	Acres	Shadow prices					
					Big tractors ($/h)	Planters ($/h)	Combine ($/h)	Dryer ($/pont)	Field labor ($/h)	Drainage mgmt time (h)
Aug 30-Sep 19	12.3	Corn, Beans	drainage	2109						105.45
Sep20-Sep 26	4.2	Beans	combine	138.15						
Sep 27-Oct 10	8.2	Corn	combine	173.07			220.93			
		Beans	combine	429.74						
Oct 11-Oct 31	12.2	Corn	combine	579.78			176.54	0.01		
		Beans	combine	403.03						
Nov 1- Nov 14	8.1	Corn	combine	453.34			116.81		10	
		Beans	combine	217.42						
		Beans	chisel	665.42						

Table 1. Crop Activities by Period-Calendar of Events and Shadow Prices for Corn-Soybeans Rotation with Controlled Drainage (Continued)

					Shadow prices					
Period	Good field days	Crop	Operation	Acres	Big tractors ($/h)	Planters ($/h)	Combine ($/h)	Dryer ($/pont)	Field labor ($/h)	Drainage mgmt time (h)
Nov 15 - Dec 5	9.9	Corn	combine	293.82					10	
		Corn	P&K spreader	1500						
		Beans	combine	311.66						
		Beans	chisel	834.58						

Note: Post-planting activities include: sprayer, anhydrous, drainage

Table 2. Crop Activities By Period - Calendar of Events and Shadow Prices for Corn-Soybeans Rotation without Controlled Drainage

Period	Good field days	Crop	Operation	Acres	Shadow prices: Big tractors ($/h)	Planter ($/h)	Combine ($/h)	Dryer ($/pont)	Field labor ($/hour)
Dec6-Apr21	9.3	Beans	chisel	12.84					
Apr22-Apr25	1.3	Corn	field cult	4.79	1117.17				
		Beans	field cult	400.4					
Apr26-May 2	2.4	Corn	field cult	748.05	1107.17	238.01			10
		Corn	planter	752.84					
May3 -May 9	2.4	Corn	field cult	614.69	1107.17	94.71			10
		Corn	planter	614.69					
		Beans	field cult	133.36					
		Beans	planter	138.15					
May10-May16	3.1	Beans	field cult	966.23	1109.07				8.09
		Beans	planter	810.52					

Table 2. Crop Activities By Period - Calendar of Events and Shadow Prices for Corn-Soybeans Rotation without Controlled Drainage (Continued)

Period	Good field days	Crop	Operation	Acres	Shadow prices				
					Big tractors ($/h)	Planter ($/h)	Combine ($/h)	Dryer ($/pont)	Field labor ($/hour)
May17-May23	3.1	Corn	field cult	132.47					
		Corn	planter	132.47					
		Beans	planter	551.33					
May24-May30	3.8	Corn	post-planting	752.8					
May 31-Jun6	3.8	Corn	Post-planting	614.7					
		Beans	post-planting	138.2					
Jun 7-Jun13	3.5	Beans	post-planting	810.5					
Jun 14-Jun 20	3.5	Corn	post-planting	132.5					
		Beans	post-planting	551.3					
Sep20-Sep 26	4.2	Beans	combine	138.15					

Table 2. Crop Activities By Period - Calendar of Events and Shadow Prices for Corn-Soybeans Rotation without Controlled Drainage (Continued)

Period	Good field days	Crop	Operation	Acres	Shadow prices				
					Big tractors ($/h)	Planter ($/h)	Combine ($/h)	Dryer ($/pont)	Field labor ($/hour)
Sep27-Oct10	8.2	Corn	combine	115.09			186.79		
		Beans	combine	472.25					
Oct11-Oct31	12.2	Corn	combine	637.76			146.91	0.01	
		Beans	combine	360.51					
Nov1-Nov14	8.1	Corn	combine	498.67			104.94		
		Beans	combine	184.18					
		Beans	chisel	657.77					
Nov15-Dec 5	9.9	Corn	combine	248.49					
		Corn	P&K spreader	1500					
		Beans	combine	344.9					
		Beans	chisel	829.39					

Table 3. Annual Economic Budget, Baseline Solution

	With controlled drainage		Without controlled drainage
	with subsidy	without subsidy	
Cash inflows			
Returns above variable costs	705,683	705,683	622,319
Cash outflows			
Annual cost of controlled drainage structure for the whole field	16,575	33,750	
Returns after drainage costs	689,108	671,933	622,319

Table 4. Estimated Value of the Opportunity Cost of Time Devoted to Managed Drainage, Baseline Solution

Full-time field labor	Additional part-time hired labor (hours)	Total hours per period used for managed drainage	Time opportunity cost of managed drainage ($/hour)
Dec. 6 – Apr. 21	108.69	300	10
Apr. 26-May 2	4.93	0	10
May 3 – May 9	4.93	0	10
May 10 – May 16	0	0	9
Nov. 1-Nov. 14	1.25	0	10
Nov. 15-Dec 5	0	0	10

Table 5. Estimated Value of the Opportunity Cost of Time Devoted to Managed Drainage with Boards Installation and Removal Allowed During Dec. 6 – April 25

Full-time field labor	Additional part-time hired labor (hours)	Total hours per period used for managed drainage	Time opportunity cost of managed drainage ($/hour)
Dec. 6 – Apr. 21	95.31	286.63	10
Apr. 26-May 2	4.93	0	10
May 3 – May 9	4.93	0	10
Nov. 1-Nov. 14	1.25	0	10

Table 6. Estimated Value of the Opportunity Cost of Time Devoted to Managed Drainage with Boards Installation after Harvest Allowed During Nov. 1 – Apr. 21

Full-time field labor	Additional part-time hired labor (hours)	Total hours per period used for managed drainage	Time opportunity cost of managed drainage ($/hour)
Apr. 26-May 2	4.93	0	10
May 3 – May 9	4.93	0	10
Nov 1-Nov 14	109.93	119.73	10
Nov 15 – Dec 5	0	30.27	10

Table 7. Sensitivity Analyses with Respect to Fuel and Nitrogen Prices

	10 % increase in nitrogen price			55% fuel price increase		
	with controlled drainage		Without controlled drainage	With controlled drainage		Without controlled drainage
	with subsidy	without subsidy		with subsidy	without subsidy	
Cash inflows						
Returns above variable costs	698,978	698,978	616,169	690,833	690,833	607,469
Cash outflows						
annual cost of controlled drainage structure for the whole field	16,575	33,750		16,575	33,750	
Returns after drainage costs	682,403	665,228	616,169	674,258	657,083	607,469

Table 8. Economic Budgets with 10 (left) and 5 (right) Acres per Drainage Structure Assumption

	With controlled drainage		Without controlled drainage		with controlled drainage		without controlled drainage
	with subsidy	without subsidy			with subsidy	without subsidy	
Cash inflows				**Cash inflows**			
Returns above variable costs	675,907	675,907	622,319	Returns above variable costs	648,416	648,416	622,319
Cash outflows				**Cash outflows**			
annual cost of controlled drainage structure for the whole field	33,450	67,500		annual cost of controlled drainage structure for the whole field	67,200	135,000	
Returns after drainage costs	642,457	608,407	622,319	Returns after drainage costs	581,216	513,416	622,319