Appendix 1-b

CROP DIVERSIFICATION - MULTI CROPPING VS. MULTI HERBICIDE-TILLAGE METHODS[1]

by

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Abstract

An Integer Programming model on a representative eastern Nebraska farm was used to analyze cropping system mixes, herbicide-tillage system mixes, and mixes of both. The results demonstrated that significant increases in revenues arise from each mixing method as well as the two together. The increased efficiency arises from reduced machinery and labor requirements.

CROP DIVERSIFICATION - MULTI CROPPING VS. MULTI HERBICIDE-TILLAGE METHODS

Much of U.S. midwestern cropping agriculture is practiced using diversified cropping. This has been a long practice frequently growing corn, soybeans, wheat, oats, alfalfa, and other crops. In recent decades corn and soybeans are the predominant crops with rotations the vehicle commonly used in the diversification process. Crop diversification does not necessarily require crop rotations, and the term diversification generally is directed to a risk context. However, risk is largely ignored in this paper. Thus, the term multi cropping is used here to denote multiple crops grown in a rotation context with the risk benefits associated with those rotations ignored.

While multiple cropping may provide useful inputs to livestock, multiple cropping is also common on farms having no livestock. One reason for this is the benefit derived from distributing labor and machinery across time using multiple crops as opposed to the need to meet the large labor and machinery requirements in short time periods (windows) for just one crop. This benefit becomes manifested in lower labor and machinery requirements (and costs) for multiple-crop farms compared to single-crop farms. Where rotations provide yield interactions, this results in another economic benefit derived from multi cropping.

Benefits from labor and field time "spreading," however, can extend beyond crop mixing to various herbicide-tillage systems used in crop production. Again, to remove the risk context, this is termed multi herbicide-tillage (H-T) systems hereafter in this paper. This opportunity occurs because different herbicide-tillage systems have different field time requirements during critical time periods (windows) in the same way that different crops do. Herbicide-tillage systems refer to the preplanting, planting, and weed control phases of crop production. These systems use different machines and different levels of field machine time during different time periods, have different herbicide requirements, involve different levels of hand weeding, and have different operating costs. Thus, it can be seen that there are considerable combinations of herbicide-tillage methods which could be used even if only one crop is grown. Again, to the degree that this mixing of methods acts to spread resources across more time periods, there is potential economic benefit.

Producers commonly report having more than one herbicide-tillage system currently in place. Often it is suggested that this is because unusual weather may occur forcing producers to make adjustments in plans. It is also frequently suggested that the reasons for multiple systems are that producers are experimenting with each and are transitioning to the most favorable. Yet, having multiple herbicide-tillage systems may be an optimal strategy in a long-run profit maximization context. If so it is important to quantify how diversification in herbicide-tillage methods both compares and interacts with multi cropping.

A range of multi methods-multi cropping is possible. At one extreme is one crop with one herbicide-tillage method. A second level is multiple cropping using one herbicide-tillage method. On the other hand, multi H-T systems could be used with one crop. The highest level of mixing is multiple crops and multiple herbicide-tillage methods, where each crop of the cropping system does not necessarily involve the same proportion of herbicide-tillage methods as other crops in the rotation.

Given the existing degree of both multi cropping and multi herbicide-tillage systems practiced on farms, it is important to separate the independent effects of each. At one extreme it can be hypothesized that benefits to multi cropping are over emphasized because multiple herbicide-tillage systems may allow the same benefits to be derived using only one crop. At the other extreme it can be hypothesized that multi cropping engages even greater benefits than previously thought because diversified herbicide-tillage systems may interact with multi cropping to provide even more opportunities to practice an agriculture which spreads labor and field machine time.

Objectives

The objective of this analysis is to quantify the independent and co-dependent effects of crop mixes and herbicide-tillage mixing on returns to land for a specific location. The effect of H-T systems are observed when single and multiple H-T systems are analyzed for a single cropping system. The effect of crop mixing is observed by holding H-T systems constant and observing the effect of crop mixing. Last, both cropping systems and H-T systems are allowed to mix.

General Procedure

A representative farm situation was constructed in a mixed integer framework. The integers were power, tillage, and harvesting machines along with labor in one-half person units. Activities were constructed to use four crops to form eight cropping system alternatives. For two crops (corn and soybeans) three H-T systems could be selected. These were conventional, low chemical, and no-till. For oats, two methods were assumed available (conventional and no-till).

Program rows engaged machine operation in association with several time periods or "windows" during which specific crop operations were required to be completed. Larger or more machinery and/or more labor units enabled the firm to grow those crops with more constraining time limitations, if profitable.

All costs except land were included in the model. The model was constructed such that any crop and any cropping system for all H-T methods could be "forced." Also, any H-T system could be forced allowing various degrees of crop system mixing.

Setting and Model Detail

Eastern Nebraska is the setting for the analysis. Four crops were considered, corn, soybeans, oats, and alfalfa. For each crop, machinery operations were specified in eleven or less critical time periods. These time periods and the estimates of field time in each are described in a later section.

In 1993 a machinery dealer provided new costs and estimates of field performance for three tractors, three disks, three field cultivators, three conventional and three no-till planters, one conventional drill and one no-till drill, one rotary hoe, three cultivators, one alfalfa windrower, one alfalfa baler, and three combines - each with corn and grain head alternatives. These were included in the model as integer choices. Ownership cost estimates for machines are described in a later section. An integer variable was included for labor in one-half person units. A $14,000 charge for each one-half person unit was included. Machine operating costs were included in machine operating variables. Other costs such as seed, fertilizer, and pesticides unique to each crop were subtracted from gross returns for each crop. Thus, all costs except land were estimated and included in the model. Commodity programs were not examined in the model. Only two of the eight cropping systems would meet program acreage requirements with program bases and flex reflective of current practices which is program base at slightly higher than one-half of crop acres. This analysis then represents basic economic analysis without program effects because the inclusion of program effects would require a base expansion or contraction path.

A strict linkage of planter rows, cultivator rows, and combine head rows was maintained for conventional and low chemical production in corn. Similarly planting and cultivation for soybeans under conventional and low chemical options. For no-till the cultivation process for corn is irrelevant to this linkage and for soybeans the no-till option requires no linkage at all. Hence, illogical mixing (for example a six row planter and a four row combine head) was not allowed in the model.

Yield interactions between crops were included for some rotations. Space does not permit a listing of these, however corn and soybean interactions tended to range from 5 to 7.5 percent. They follow results of experimental data and that described in Friesen. Budgets for costs followed closely those described by Selley, et al.

For a given farm size the model selected the optimum mix of crops, machinery set, and labor unit. As subsequently discussed, two input capacity forces had particular impact on resource (and output) decisions. These were set-up charges on the integer labor variable and the fixed charge component for machine selection due to interest on investment. Both lead to pressures to utilize these variables to full capacity. The overall matrix size was roughly 300 by 400.

Cropping Systems and Herbicide-Tillage Systems

Four crops (corn, soybeans, oats, and alfalfa) were used in forming six crop rotations. These were corn-soybeans (C-SB), corn-soybeans-soybeans (C-SB-SB), corn-corn-soybeans (C-C-SB), corn-oats-alfalfa-alfalfa (C-O-A-A). corn-soybeans-oats-alfalfa (C-SB-O-A), and corn-soybeans-corn-oats-alfalfa (C-SB-C-O-A). These six along with continuous corn (C) and continuous soybeans (SB) provided the eight cropping systems analyzed.

Three herbicide-tillage systems were studied. A conventional (C_V) system for corn and soybeans employs broadcasted herbicides and one cultivation along with preplant tillage.

For the low chemical option (L) a rotary hoe and two cultivation operations are used for post plant tillage along with banded herbicides. For no-till, preplant tillage does not occur and no cultivations or rotary hoeing occurs, however a "burndown" operation using additional herbicides beyond that used in the conventional option is included. Some hand weeding occurs with all three operations and this varies across the three alternatives wit the greatest hand labor requirement under the low chemical option.

Critical Field Time "Windows"

One of the most important components of the model was the critical time period limits to accomplish field tasks. Estimates, using meteorological data on precipitation resulted in average 10-hour days available in 11 time periods. To reduce risk these were reduced by 25 percent such that a higher probability of completing operations in unusual years would occur. The time periods are listed below:

1) Spring preplant for corn, oats, and soybeans and planting corn and oats. April 15 - May 8.

2) Spring preplant and plant for soybeans. May 9 - June 1.

3) Alfalfa harvesting imbedded window of 2 above. May 15 - June 1.

4) Rotary hoeing of corn and soybeans. June 1-9.

5) Cultivation 1 (low chemical and convention corn and soybeans). June 10-22.

6) Cultivation 2 (low chemical corn and soybeans) and alfalfa harvesting 2. June 23 - July 7.

7) Combine oats. July 10-28.

8) Alfalfa harvesting 3. Aug. 1-15.

9) Soybean combining 1. Oct. 7-21.

10) Soybean combining 2 and corn combining 1. Oct. 22-30.

11) Combine corn. Nov. 1-21.

Also, if desired the model could choose to plant soybeans in the second spring period with preplant operations completed in the first period. Hand weeding requirements took place in period 7 and 8.

Intensity Based Vs. Assumed Hour Based Costs For Depreciable Assets

In optimization models where the objective function for an input changes as the input use changes, a problem can occur unless a process exists to correctly specify the linkage of the cost to use. If not, the resultant input use may vary considerably from that use originally assumed in developing the cost. In such a case little confidence can be placed in the optimization process.

In this problem there are four aspects of machine ownership costs which require attention to maintain a bias-free model. These are 1) depreciation, 2) repairs, and 3) interest on investment.

Depreciation

Use is generally regarded as highly related to a machine's remaining value. While remaining value functions may not be linear with use (usually perceived as convex) such as assumption is not unrealistic for estimating an average cost per hour over a machine's lifetime. Thus, original costs less salvage value are divided by lifetime hours of use.

Repairs

Cumulative repair function estimates are published for various machine classes (ASAE). While these are not linear, a linear assumption is not unrealistic because only an average is desired in annual-based models. Thus, cumulative repair costs are divided by hours of use.

Interest on Investment

Assuming machine life (H) in hours and initial machine cost (V_o), depreciation (d) on an hourly basis is

1) $d = (V_o - SV)/H$ where SV represents salvage value

The depreciation cost per year is

2) $D = dX$ where X is the hours of use per year

In capital budgeting the annualized interest charge can be shown to be approximated by

3) $$I = \frac{(V_o - SV + D)}{2} i$$

where i is the annual interest rate. Substituting (2) into (3) one obtains

$$4) \quad I_D = i\frac{(V_o - SV)}{2} + \frac{id}{2}X$$

The annual interest on investment cost consists of a fixed component (the first term) which is independent of the intensity of use and a variable component which increases with use (X). In equation 4 per unit interest costs decrease with greater intensity of use while total annual interest costs increase as the useful life of the asset is shortened. Thus, the economic pressure for greater intensity of machine use due to the resultant reduction of average interest costs is properly modelled if a linear approximation (as a function of use) to the remaining value function is satisfactory.

Results

Herbicide-Tillage Mixes

The effect of herbicide-tillage mixing is summarized by Table 1. For each crop system, optimum returns were determined 1) by allowing only one H-T alternative, 2) by allowing a mix of H-T but each crop of each system is required to have the same H-T alternative, and 3) allowing a full mix of crop systems as well as H-T alternatives so that each crop of each crop system could employ a different H-T choice.

Overall, for single H-T systems, the low chemical and no-till systems dominate the conventional H-T system. Cropping systems involving oats and alfalfa performed very poorly under the study assumptions. Yet systems involving high proportions of corn also performed poorly demonstrating the high resource requirements of corn in particular "windows."

When mixing of H-T systems is allowed, returns are significantly enhanced for continuous corn, corn-soybeans, and corn-corn-soybeans. For the three cropping systems involving oats and alfalfa, a single H-T remains dominate over potential mixed H-T systems. It can be seen that in every case, mixing of systems involved low chemical and no-till systems.

Only slight increases are found when the last step is allowed (mixed H-T per crop of the rotation). Thus, advantages of mixed herbicide-tillage systems are nearly all realized in full rotation sequences where for each rotation system, H-T practices are the same.

Crop Mixes

Holding herbicide-systems constant, the effect of crop mixing is demonstrated in Table 2. For each of the three H-T systems, optimum solutions were obtained for 1) single crops, 2) the two single crop systems and six multi-crop systems, and 3) cropping system mixes. For the latter two only the optimal solutions are presented.

For single crop, single H-T systems the no-till systems always performed poorly. Also, except for soybeans grown conventionally or in a low chemical manner the remainder of the single crop, single H-T systems performed poorly.

When one rotation was allowed, the no-till H-T system "reversed" itself by outperforming the conventional and low chemical alternatives ($47,591 vs. $34,977 and $39,155 respectively). This was accomplished in a corn-soybean-soybean crop mix. For the conventional H-T choice, crop mixes did not result in any advantage. For the low chemical option, only a very slight advantage ($39,155 vs. $39,070) was realized by a corn-soybean-soybean rotation vs. the continuous soybean option.

When mixes in rotations were allowed, significant and roughly equal increases in returns were realized for each H-T alternative. The optimum levels of crops in such cases involved high proportions of soybeans compared to corn.

Crop System, Herbicide-Tillage Interaction

It can be noted that the maximum programmed returns to land are $55,284 from Table 1. This results from a corn-soybean rotation in which 222 of 400 acres of the corn and 50 of 400 acres of the soybeans were grown under a low chemical option and the remainder under no-till. Note that this return cannot be reached by the corn-soybean rotation of Table 1 using mixes of low chemical and no-till where the proportion must be the same for both crops ($54,244). Similarly from table 2 note that the maximum return achievable with one tillage regime is for no-till using corn-soybean and corn-soybean-soybean rotations ($53,152). Thus, while this difference between $55,284 and either $54,244 or $53,152 is not great, it demonstrates that mixing of crops as well as mixing H-T systems is the optimal choice. Neither one H-T system accompanied with a crop mix nor one crop rotation using a mix of H-T systems was able to achieve the maximum return.

Summary

Using a mixed integer programming model constructed for an eastern Nebraska representative dryland farm, the effect of both crop mixes, herbicide-tillage mixes, and mixes of both were analyzed. Various crop and herbicide-tillage systems employ field time in different proportions by system. Hence, advantages of mixed systems may arise from both sources. Eight cropping systems and three herbicide-tillage systems were examined.

The results demonstrated that both sources can contribute to increased economic returns. Mixing herbicide-tillage for any given crop system led to markedly improved efficiency. That mixing was accomplished by low chemical and no-till systems. Similarly for a given herbicide-tillage system, returns were markedly improved by 1) the use of a mixed crop system (rotation) and 2) further by mixing rotations. Highest returns were achieved when mixed crop and herbicide-tillage systems were employed but where the herbicide-tillage treatment varied between crops of the rotation.

These results suggests that there are two basic alternatives to reduce the problems and costs in meeting machine and labor requirements during critical time period (windows). While crop mixing is traditional, this analysis suggests that herbicide-tillage mixing is similarly useful.

Table 1. Mixed Integer Programming Results of Effect of Three Herbicide-Tillage Mixes on Returns to Land.

Cropping System	One H-T System[1]		Multi Cropping Systems - Multi H-T Systems					
			Same H-T Per Crop of System			Variable H-T Per Crop of System		
	H-T	$	H-T	Ac.	$	H-T	Ac.	$
Continuous Corn (C)	L	9,779	C_L	543	22,009		N.A.	
			C_N	257				
Continuous Soybeans (SB)	L	39,070	SB_L	505	40,403		N.A.	
			SB_N	295				
Corn-Soybeans (C-SB)	N	40,665	C-SB_L	181	54,244	C_L	222	55,284
			C-SB_N	219		C_N	177	
						SB_N	350	
						SB_L	50	
Corn-Soybeans-Soybeans (C-SB-SB)	N	47,951	C-SB-SB_L	185	50,449	C_L	267	51,457
			C-SB-SB_N	82		C_N	323	
						SB_N	211	
Corn-Corn-Soybeans (C-C-SB)	L	11,901	C-C-SB_L	133	24,476	C_L	533	25,179
			C-C-SB_N	133		C_N	200	
						SB_N	267	
Corn-Oats-Alfalfa-Alfalfa (C-O-A-A)	L	-81,469	C-O-A-A_L	800	-81,469	C-O-A-A_L	800	-81,469
Corn-Soybeans-Oats-Alfalfa (C-SB-O-A)	L	-393	C-O-A-A_L	800	-393	C-O-A-A_L	800	-393
Corn-Soybeans-Corn-Oats-Alfalfa (C-SB-C-O-A)	L	15,524	C-SB-C-O-A_L	800	15,524	C-SB-C-O-A_L	800	15,524

[1] Maximum return herbicide-tillage alternative for each cropping system.

Table 2. Mixed Integer Programming Results of Effect of Five Crop Mixes on Programmed Returns to Land.[1]

	Single Crop		Single Crop Systems			Crop System Mixes			
	H-T	$	H-T	Crop System	$	H-T	Crop System	Ac.	$
Corn	N	5,441	N	CBB_N	47,591	N	C-SB	314	53,152
	C_V	9,779					C-SB-SB	58	
	L	2,494							
Soybeans	N	9,198	C_V	SB_C	34,977	C_V	SB	468	41,331
	C_V	34,977					C-SB	166	
	L	39,070							
Oats	C_V,L	-37,818	L	CBB_L	39,155	L	SB	301	46,389
	N	-57,502					C-SB-SB	166	

[1] Maximum return solution for each of three herbicide-tillage alternatives.

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