DETERMINING LABOUR EFFICIENCY OF U.S. ROW CROP PRODUCTION

Gregg Ibendahl and John Anderson
Department of Agricultural Economics, Mississippi State University,
P.O. Box 5187, Mississippi State, MS 39762, USA.
Email: ibendahl@agecon.msstate.edu

Abstract

Technology is continually improving the technical efficiency of agriculture. Advances in seeds, chemicals, machinery, and other inputs are allowing farmers to produce more than ever before and with fewer inputs. In addition, the available supply of agricultural labour has been shrinking. One problem facing producers is determining what practices lead to labour savings and where is additional labour savings likely to occur. As quality labour becomes more expensive and difficult to obtain, producers will want to know how best to allocate their resources in order to obtain maximum labour efficiency. This paper uses seven years of farmer data from cotton and soybean production to develop a model that shows the factors determining the hours of labor required to produce each of the crops. The model is based on a regression analysis of 900 farmer observations from the Mississippi delta. In addition, the model shows how effective each factor is for reducing labour and whether the factor is more important for cotton or soybeans. Results show that farm size, field size, percent rented land, percent of farm planted to soybeans or cotton, percent custom expenses, percent GMO seed varieties, and row spacing can all be important factors determining labour hour requirements. Bigger farms have economies of scale for both cotton and soybean farms. However, the coefficient for cotton is twice as large meaning that cotton farms see a bigger gain in labour reduction by expanding than do soybean farms. The use of GMO had a similar effect as it both reduced labour and was more effective for cotton than soybeans. The major difference between cotton and soybean farms was in the degree of specialisation. For cotton farms, adding more cotton reduced labour while for soybeans, adding more increased labour. These results indicate that cotton farms are likely to continue to expand and also be more specialised. Farms growing soybeans are likely to grow a mix of crops but will continue to expand as well. These results should be useful to producers looking for ways to save labour and also to policy makers considering minimum wage laws and payment programs that might limit farm size.

Keywords: labour, efficiency, cotton, soybeans, production

Background

As might be expected, data about farm labour use has existed for a long time. For example, the number of agricultural workers in a state can be found back to at least the year 1800 (http://eh.net/databases/agriculture/). At a very aggregate level, the number of labour hours required to produce a crop can be calculated by dividing the labour hours available by the number of acres of a crop produced.

Some published estimates of crop production labour go back to the 1800's as well. According to Welch and Miley (1950), 601 hours were required to pick a single bale of cotton. By 1925 this had dropped to 269 hours and by 1945, labour per bale was down to 182 hours.

More recent data from the USDA shows how dramatically labour hours to produce a crop acre have decreased.

Figure 1: Labour hours to produce an acre of cotton and soybeans

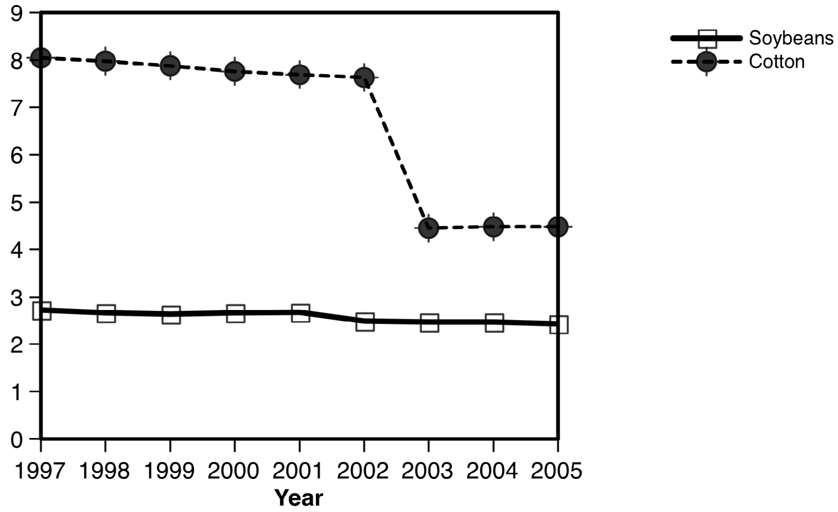


Figure 1 is based on the USDA's Agricultural Resource Management Survey (ARMS). This survey estimates the costs to produce an acre of crop. The labour cost is converted to hours by dividing by a labour rate per hour. As Figure 1 shows, the time requirement is under five hours per acre for both crops. Sampling by the USDA changed in 2003 explaining the big jump in cotton for that year.

Labour required to produce a given crop acre has declined for two reasons. First, out of necessity as the available supply of labour has been shrinking since the 1900's. Mundlak (2005) shows that throughout the 1800's land, labour, and capital all increased with growth rates ranging from one to three percent. From 1900 to 1940, the agricultural labour supply started to decrease by 0.5% while the growth rates of land and capital slowed to a positive 0.5%. Since 1940, labour has decreased at a 2% rate and land has decreased at a 0.5% rate.

The second reason labour requirements for crop production have decreased is technical innovation. These technological changes can be divided into mechanical and chemical. For the mechanical changes, the most important factor has been the development of the cotton harvester. As shown in Peterson and Kislev (1986), the percent of cotton mechanically harvested went from 6% in 1949 to 96% in 1969. Mechanical changes occurred at a faster rate from 1950 to 1970 than they did from 1930 to 1950 (Kislev and Peterson, 1982). Other mechanical changes include better and larger planters as well as new tools and techniques to get the cotton from the field to the gin. The development of the boll buggy and module builder was nearly as revolutionary as the mechanized cotton picker.

Chemical changes are many and include new herbicides and insecticides and better defoliating tools. Related to chemical changes in both cotton and soybeans, is the development of genetically modified (GMO) seed. For cotton, GMO seed has resulted in Bt varieties that reduce or eliminate the need to spray insecticides. Bt cotton has been shown to have economic benefits to farmers as well (Pray and Ma, 2001). For both cotton and soybeans, GMO seed has also resulted in glyphosate-tolerant or "Roundup Ready" varieties. These latter GMO products allow producers to use glyphosate as a weed control herbicide. Glyphosate (Roundup) can result is labour savings as it may reduce trips over a field and is less time sensitive to application.

Peterson and Kislev (1986) examine which is the most important factor in the reduction of crop production labour. Has it been the reduction in supply of agricultural labour or has it been technological change reducing the need for labour? In the former case, technology was developed to fill the gap as labour left. Peterson and Kislev conclude that the pull effect of labour leaving the farm is four times greater than technology pushing labour away.

Model and Data

Every year in Mississippi a survey is conducted of producers to determine the cost of production for all the major crops grown in the state. This is a phone survey of around 150 producers. The survey consists of some basic questions about acres owned, acres rented, acres of each crop grown, types of seed planted, irrigation, and rental information. The bulk of the survey though is about a specific field and the operations applied to that field. Every trip over that field is recorded as an operation and these questions ask about what was done during that trip and the type and size of equipment used. In addition, if the field operation involved planting, spraying, or fertilization, then the material and rate is also recorded.

The survey does not specifically ask for labour hours or any costs associated with the field operations. These are brought in from a database of machinery and material cost items. For example, planting a specific seed variety with specific size planter and tractor will generate a labour time and costs for the tractor, planter, and seed that is taken from the cost database. Producers probably do not have a good time and cost estimate at the field level but do have good information about what was done to the field on each trip across the field. Taking the field operation information and applying the typical associated costs for the machines and material used gives a better estimate of costs and time than if farmers tried to provide this information directly.

The econometric model is based on 910 observations for cotton and 947 observations for soybeans. Different producers are surveyed for each crop and the mix of producers used each year is different. For the analysis in this paper, separate econometric models were developed for each crop.

The independent variable is the number of hours per acre required to produce either an acre of cotton or an acre of soybeans. The labour hours include operator labour, hand labour, and irrigation labour. Operator labour hours are those associated with operating a piece of equipment (i.e., cotton picker, tractor, etc). Hand labour hours are extra time needed to perform the various field operations which are not time directly on the machine. For example, planting requires extra time to fill the planter boxes. This hand labour is usually a lower skilled, lower paid source. Irrigation labour hours are associated with operating irrigation equipment.

In addition to these three sources of direct labour there is unallocated labour that is difficult to pin down to a specific field operation. This labour amount is estimated as a function of the other costs. However, this unallocated labour is not included in the analysis as it is just based on other data. As a result, the labour totals per acre will likely appear low compared to some other estimates of labour. This does not affect the analysis of what drives labour use in crop production.

Figure 2: PDF approximation of the labour hours per acre – cotton and soybeans

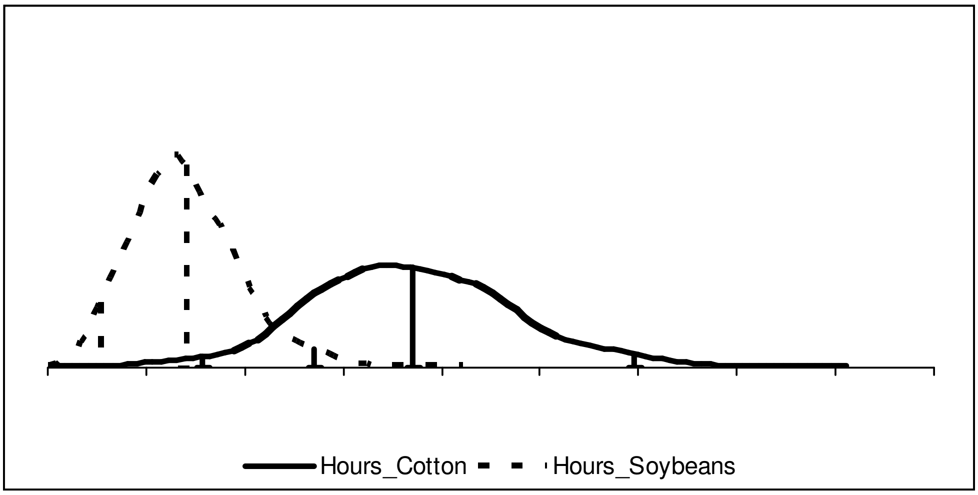


Figure 2 shows the probability density functions (PDF) for the labour hours required to produce an acre of cotton and an acre of soybeans. As the graph indicates, the mean hours for soybeans are less than the mean hours for cotton. In addition, the variance for cotton labour hours is greater. Specifically, the mean soybean and cotton labour hours per acre are respectively: 0.70 and 1.85 hours. The respective variances of soybean and cotton labour hours per acre are: 0.08 and 0.30. As mentioned above, this is only the directly measured labour hours. The unallocated labour could add 50% or more to the labour totals.

Table 1: Descriptive statistics for some cotton variables

Variable:	Crop Acres	Soybean Acres	Soyean acres Irr	Non-GMO	Direct exp	Fixed exp	Yield
Min.:	12	12	-	-	41	2	2
Max.:	13,621	8,926	6,700	5,200	203	95	70
Mean:	1,402	759	203	183	95	27	30
Median:	925	456	-	-	91	23	30
Variance:	2,498,270	684,602	283,100	237,997	572	259	163
Std. Dev.:	1,581	827	532	488	24	16	13
Std. Err.:	51.86	27.15	17.46	16.01	0.78	0.53	0.42
Skewness:	2.88	2.78	4.84	4.87	0.81	1.29	0.06

Table 2: Descriptive statistics for some soybean variables

Variable:	Crop Acres	Cotton Acres	Cotton acres Irr	Non-GMO	Direct exp	Fixed exp	Yield
Min.:	12	12	-	-	185	9	44
Max.:	13,700	10,200	8,000	3,500	642	162	1,700
Mean:	1,641	990	363	88	354	72	792
Median:	1,195	700	-	-	349	68	800
Variance:	2,416,270	989,229	532,104	88,381	4,975	598	59,860
Std. Dev.:	1,554	995	729	297	71	24	245
Std. Err.:	51.84	33.17	24.33	9.92	2.35	0.82	8.16
Skewness:	2.50	2.99	3.96	6.34	0.33	0.43	0.03

Tables 1 and 2 list some of the descriptive statistics about the farms used in the analysis. This table has the crop acres, soybean/cotton acres, soybean/cotton irrigated acres, acres of non-GMO seed, direct expenses per acre, fixed expenses per acre, and yield per acre. As can be seen, most of the farms are fairly large with a mean size of 1,500 acres. This is certainly bigger than the typical U.S. farm but is fairly typical of full-time farms in the Mississippi delta.

It should also be pointed out that the number of acres planted to non-GMO seed is fairly small. While the data range for this dataset captures some of the transition to GMO seeds, the transition was well underway by the first year of this data. By the last year of the dataset nearly all the cotton seed and a majority of the soybean seed is GMO based.

Results

The following equation is the final form of the econometric model

$$\begin{aligned} Hr = {} & \beta_0 + \beta_1 \cdot \text{Cropland} + \beta_2 \cdot \text{Fld\_size} + \beta_3 \cdot \text{P\_rent} + \beta_4 \cdot \text{P\_AC\_cotton} \\ & + \beta_5 \cdot \text{P\_custom\_exp} + \beta_6 \cdot \text{P\_GMO\_ac} + \beta_7 \cdot \text{Is\_irr} + \beta_8 \cdot \text{Is\_skiprow} \\ & + \beta_9 \cdot \text{Is\_2004} + \beta_{10} \cdot \text{Is\_2003} + \beta_{11} \cdot \text{Is\_2002} + \beta_{12} \cdot \text{Is\_2001} + \\ & + \beta_{13} \cdot \text{Is\_2004} + \beta_{14} \cdot \text{Is\_1999} + \beta_{15} \cdot ave\_yld \end{aligned}$$

The variables in this equation are defined as follows:

Cropland – The number of acres of cropland farmed.

Fld_size – The size of the field used in the survey questionnaire.

P_rent – The percentage of crop acres that are rented.

P_AC_cotton – The percentage of crop acres planted to cotton. The soybean analysis has a similar variable.

P_custom_exp – The dollar amount of custom operation expenses divided by the total expenses. This percentage is for either the cotton or soybean acres only.

P_GMO_ac – The percentage of either cotton or soybean acres that were planted to GMO seed varieties. GMO seeds for cotton could either be Roundup Ready varieties, Bt varieties, or stacked genetics varieties (i.e., varieties containing both Roundup Ready and Bt genes).

Is_irr – A dummy variable to represent if the crop acreage was irrigated.

Is_skiprow – A dummy variable to represent skip row cotton. For soybeans, this is a continuous variable for row spacing.

Is_2004 – A dummy variable signifying crops grown in 2004. There are dummy variables for years 1999 through 2003 as well. This makes 2005 the reference year.

Ave_yld – the weighted average irrigated and dry land yield.

Other variables were investigated in the econometric analysis but these were the only ones to have any statistical significance.

Table 3: Regression results for cotton model

	Beta	S.E.	t-test	Prob(t)
Intercept	2.29367	0.11114	20.63788	0.00000
Cropland	-0.00006	0.00001	-5.64468	0.00000
Fld_size	-0.00029	0.00021	-1.38194	0.16733
P_rent	-0.05361	0.04291	-1.24921	0.21192
P_AC_cotton	-0.15617	0.05895	-2.64932	0.00821
P_custom_exp	-4.35934	0.28115	-15.50552	0.00000
P_GMO_ac	-0.12577	0.06504	-1.93390	0.05344
is_irr	0.14858	0.03394	4.37751	0.00001
is_skiprow	-0.19064	0.05767	-3.30601	0.00098
is_2004	0.01085	0.05752	0.18866	0.85040
is_2003	0.12314	0.05740	2.14530	0.03220
is_2002	-0.28730	0.05465	-5.25703	0.00000
is_2001	-0.33732	0.05676	-5.94290	0.00000
is_2000	-0.29116	0.05569	-5.22828	0.00000
is_1999	0.08241	0.05551	1.48458	0.13801
ave_yld	0.00042	0.00007	5.79017	0.00000

Table 4: Regression results for soybean model

	Beta	S.E.	t-test	Prob(t)
Intercept	0.65262	0.05096	12.80663	0.00000
Cropland	-0.00003	0.00001	-4.68119	0.00000
Fld_size	-0.00028	0.00010	-2.68882	0.00730
Row_space	0.00493	0.00079	6.21605	0.00000
P_rent	-0.06675	0.02139	-3.12114	0.00186
P_AC_soybeans	0.07891	0.02891	2.72995	0.00645
P_custom_exp	-1.15437	0.08371	-13.78994	0.00000
P_GMO_ac	-0.07985	0.02170	-3.67931	0.00025
is_irr	0.13807	0.01956	7.05792	0.00000
is_2004	0.08622	0.02803	3.07631	0.00216
is_2003	0.07312	0.02924	2.50041	0.01258
is_2002	0.00382	0.02724	0.14034	0.88843
is_2001	0.07410	0.02895	2.55940	0.01064
is_2000	0.09208	0.03004	3.06515	0.00224
is_1999	0.15426	0.02965	5.20213	0.00000
ave_yld	0.00252	0.00075	3.34844	0.00085

Tables 3 and 4 present the regression results for the cotton and soybean analysis respectively. Every variable in the soybean analysis is significant while in the cotton analysis; field size and percent rent were not significant. However, these two variables were left in so that both crop models would match. The cotton model has an adjusted R-squared of 0.38 while the soybean model has an adjusted R-squared of 0.34

All the variables have the correct sign. As farm size gets bigger, the required labour gets smaller. The coefficient is very small but this only represents the fraction of a labour hour per acre reduction caused by farming one additional acre. However, cotton labour was reduced at twice the rate of soybean labour. The presence of a negative sign on the coefficient, even in the presence of some fairly large farms, would indicate that there are still some returns to scale occurring.

Field size is only significant for the soybean analysis but its negative sign shows that there are advantages to big fields. This might perhaps represent having fields closer together rather than farther apart. Saving time on the road is probably what is occurring here.

The percentage of land rented tends to reduce labour requirements for soybean production. However, this variable is not significant for cotton.

Row spacing is only a variable for soybean production as most of the cotton was only in two row widths and these were very close together. Surprisingly, wider rows led to more labour. Perhaps weed control was a bigger issue with wider rows.

The percentage of custom operations affected both cotton and soybeans the most. This is totally expected as hiring custom work takes directly away from what the producer must provide.

The increased use of GMO seed reduced labour as well. Again this is an expected result. However, the variable is barely significant for cotton. Given that the dataset does not cover the entire GMO transition, some of the significance may have been lost. The magnitude of the GMO seed coefficient for cotton is nearly twice that of soybeans. Because cotton has two types of GMO characteristics, this is expected.

The one variable where the cotton and soybean analysis differ is for the percentage of farm acres planted to the crop in question. For cotton farms, increasing the percentage of cotton acreage decreased labour. For soybean farms, increasing the percentage of soybean acres increased labour.

Figure 3: Scatter plot of labour hours for cotton for various farm sizes

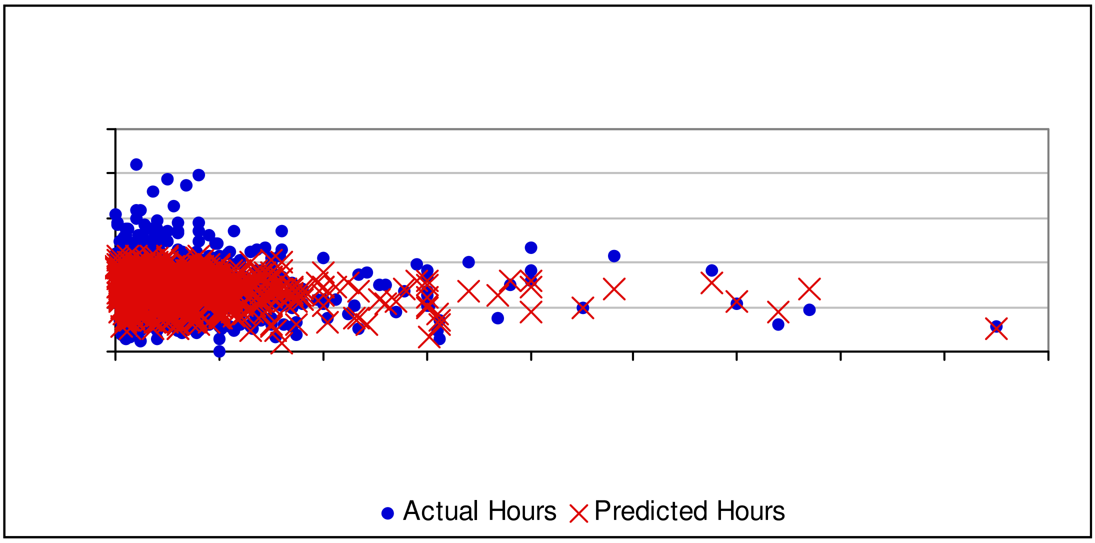
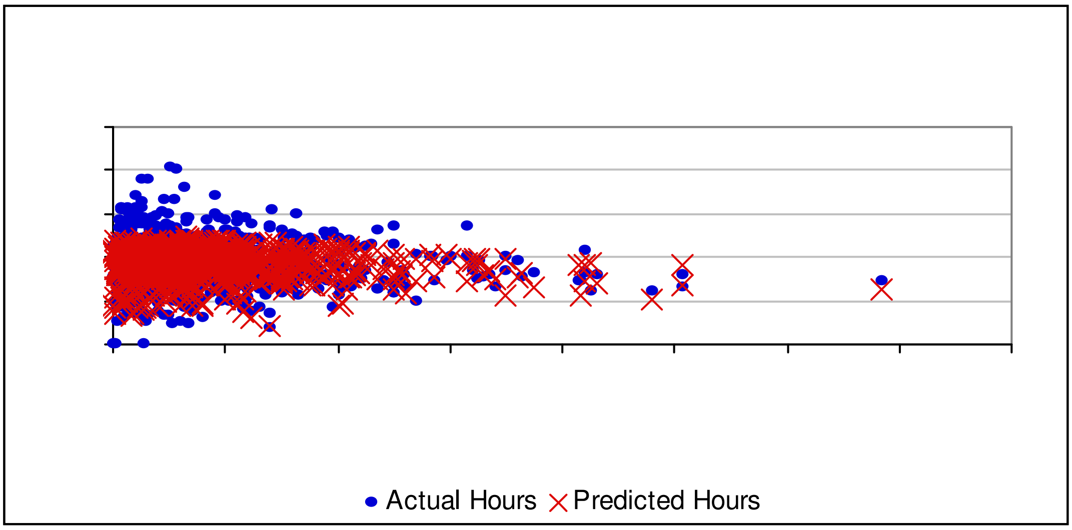


Figure 4: Scatter plot of labour hour for soybeans for various field sizes



Figures 3 and 4 show how well the model predicts labour hours. These two figures match the hours by using the variable in the analysis that appears to show the biggest deficiency. For cotton farms, the econometric model does not do all that well at predicting labour hours for the smaller farms. For the soybean farms, the econometric model visually appears to do the poorest predicting with the smaller field sizes

Conclusions and Discussions

As shown here, labour hours to produce an acre of cotton and soybeans have been reduced considerably over the last century. Based on USDA data, cotton and soybean labor hours per acre are 4.5 and 2.5 hours, respectively. Based on data collected from Mississippi producers, the direct labor hours per acre for cotton and soybeans are 1.85 and 0.70 hours, respectively.

Labour reduction is still occurring thanks to continuing improvements in mechanisation and improved seed and chemical technologies. However, the dramatic improvements in labour reduction are likely past as even in the highest cotton estimate by the USDA, cotton labour was already below five hours per acre. Thus, production changes that shaved hundreds of hours per acre are just not possible. Still, with labour becoming more scarce and expensive, any improvements in labor requirements should be welcome by producers.

Returns to scale are still occurring and are possible even with some of the bigger than average farms in the Mississippi delta. Therefore, farm size is likely to increase even more. Given that cotton farms showed a rate of improvement twice that of soybean farms, cotton farms are more likely to expand than soybean farms.

The specialisation variable in the results showed conflicting results. Cotton farms were able to reduce labour by growing more of the farm in cotton while the reverse was true of soybean farms. Thus, cotton farms are likely to become even more specialized in cotton while soybeans farms are likely to have a variety of crops grown.

GMO seed varieties have certainly help reduce labour. However, this analysis probably missed some of the labor savings as the GMO transition was well underway before this variable was measured in the dataset.

Soybeans have the lower labor requirements than cotton and probably always will. However, cotton also has the most room for improvement and shows the most promise for size expansion and improvements in mechanization and seed/chemical technologies.

This paper should be useful to U.S. policy makers because of potential changes to minimum wage laws as well as potential changes to farm policy relating to farm size. Cotton farms are some of the biggest farms and could be directly affected by a U.S. cap on government payments. If cotton farms are still showing benefits to increasing farm size then a payment cap could make U.S. agriculture less efficient. Finally, this paper should help farmers and farm managers as they make expansion decisions and allocate scare labor.

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