Per Unit Costs to Own and Operate Farm Machinery

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Introduction

Farm machinery is a vital part of most farming operations, from the physical work it performs in the production process to the enjoyment provided from its operation. As technological advancements in machinery and the crop production process evolve, farm sizes increase and profit margins often decrease. Therefore, efficient use of machinery and its contribution to a producer's relative cost of production is increasingly important.

Machinery costs can be determined from farm records or cost estimators; however, these methods often result in generalized whole farm or per machine costs, rather than per unit (e.g., acre, ton, bale, etc.) machinery costs. One alternative to calculating the myriad of machinery costs is to use custom farming rates. Custom farming rates are rates paid for an operator to perform an operation, such as harvesting, planting, tillage, etc., and are usually based on a per unit charge (i.e. acre, ton, bales, etc.). However, with the large amount of neighbor-to-neighbor work, and family custom farming done, whether published custom rates truly represent full machinery ownership and operating costs is often questioned. If the full cost to perform these operations is known, it will allow an individual farm to evaluate its relative machinery costs and allow its crop machinery costs to be benchmarked against an expected cost.

Background

Langemeier and Taylor concluded that over time machinery has been substituted for labor, thus increasing machinery costs, but utilizing labor more efficiently. They found that machinery costs (including gas, oil, repair, depreciation, interest on investment, and insurance) account for 35.5% to 46.6% of crop production costs on Kansas farms. Machinery costs ranged from $29.33 per acre on non-irrigated farms in northwest Kansas to $67.79 per acre on irrigated farms in southwest Kansas.

Given that machinery costs are a significant part of crop production, one might ask, how much do they affect profitability, and are they manageable? Albright used three years of data to sort farms into high, middle, and low profitability groups. Across seven different enterprises (non-irrigated wheat, irrigated wheat, non-irrigated grain sorghum, non-irrigated corn, sprinkler irrigated corn, non-irrigated soybeans, and non-irrigated alfalfa) there was an average $97.91 per acre difference in profit between the high and low profitability groups. Of this difference, 84% was due to costs. The difference between high and low profitability farms due to machinery costs (including repairs, machine hire, depreciation, gas, fuel and oil) ranged from $14.91 per acre for non-irrigated soybeans to $45.04 per acre for sprinkler irrigated corn. As a percentage of the total cost difference between high and low profit groups, machinery costs accounted for 28% to 44% of the total cost difference depending on the crop. These results show that a majority of the difference in profitability between farms comes from cost management, with a large part of the cost differences being machinery related.

Knowing that machinery costs are important and impact farm profitability, it is logical for producers to determine their machinery costs, but more importantly to determine their costs relative to others. These costs can be determined from actual farm records or cost estimators using sources like the American Society of Agricultural Engineers and Bowers. Unfortunately, the cost estimators are based on averages or generalizations that do not take into account the individual management abilities of a farm (Reid and Bradford; Cross and Perry). Furthermore, assumptions must be made about the field efficiency of the operations to derive per unit machinery costs from actual aggregate or estimated machinery costs. Hunt mentions that with inflation and technological changes, machinery cost estimators become inaccurate within a few years after they are estimated. A method of avoiding the downfalls of generalized assumptions and out-dated estimators would be to use a market price of performing field operations, adjusted by farm specific cost information. The market price of field operations would be custom rates which are established in the market place by custom operators providing the service (supply) and producers hiring the custom operator's service (demand).

However, if one is going to question the validity of other cost estimators, the validity of custom rates must also be questioned. Based on Illinois data, Schnitkey concluded that, on average, farmers cannot perform machinery operations at as low of cost themselves as if they had all the operations custom hired. Schnitkey estimated the annual per acre costs to own and operate machinery in Illinois. These costs included machinery repairs, machine hire, leasing, fuel, oil, light vehicle depreciation, machinery depreciation, labor, and opportunity interest on the machinery. The average annual per acre cost calculated (excluding labor and opportunity interest) to perform the operations if the machinery were owned was $62.60 per acre (average of $54.81, $71.00, and $62.00 per acre for central, northern, and southern Illinois, respectively). However, a labor charge and opportunity cost of capital charge must be included, which were estimated to be $10 per acre and $18 per acre, respectively. Therefore the average estimated cost for a producer to perform operations if the machinery were owned and operated was $90.60 per acre. Schnitkey then estimated the annual per acre machinery costs to have all operations performed by a custom operator. The custom hire cost was estimated by summing the cost of each operation, which was calculated as the product of the Illinois custom rates for a particular operation and an average number of times that operation was performed. He found the average cost for using custom operations to perform machinery operations to be "about $70" an acre ($68 for soybeans, and $75 for corn).

Since the cost to own and operate machinery ($90.60 per acre) is greater than having the operations performed by custom operators ($70.00 per acre), custom rates, on average, do not cover all costs of ownership and operation, further motivating this research. Schnitkey's research shows that, on average, one cannot use custom rates to directly calculate machinery costs. As such, estimating a "true" custom rate or a rate that on average covers all ownership and operating costs will be valuable to producers wanting to prorate machinery costs to specific operations or enterprises.

With the above mentioned "true" custom rates, an individual farm will be able to determine its relative standing to other farms (i.e., benchmark), with regard to machinery costs. Benchmarking is the process where an individual compares individual characteristics, such as costs, revenue, profits, and production measures with the average of the whole group to which that individual belongs. Benchmarking is especially useful for characteristics where an individual's management abilities make a difference. Farm machinery costs are one area in which benchmarking can prove to be a useful tool.

According to Schuster, in industries with increased competition, consolidations, and where cost cutting is important, benchmarking provides a means to see ones relative standing. It allows managers and operators to determine in which areas they are performing above, at, or below average. As previously discussed, machinery costs are a large portion of crop production costs and therefore could be a very useful category to benchmark. Schuster points out that external benchmarking can be used to compare across firms in the same industry, enterprise, time period, and geographic region to note differences in productivity and performance. A farm manager can use external benchmarking to see if machinery operations are a strength or a weakness to the individual farm. If the farm is performing machinery operations for less than the true custom rate, then machinery costs are a strength for the farm. If the farm is performing machinery operations for more than the true custom rates, then machinery costs would be a weakness and the farm might consider "out sourcing," or having someone else perform the machinery operations by hiring custom work to be done.

Models

The underlying conceptual model of this research is based on the premise that crop machinery costs are dependent upon the field operations performed and the size of the farm, with farm size being represented by harvested acres, and is characterized as

(1) tcmc = f(field operations, harvested acres).

The dependent variable is the total crop machinery cost (tcmc) for a farm, and the independent variables are the number of units (acres, tons, bales, etc.) each of the individual farming operations were performed on as well as the total harvested acres for the given farm. The conceptual model above was empirically specified with four different functional forms to capture the scale or size effect of farms. The functional forms include linear, quadratic, reciprocal, and logarithmic. The empirical specification of the linear model (model 1) is the following

$$(2)\quad tcmc_i = [\beta_1 fcwof_i + \beta_2 swof_i + \beta_3 dsk_i + \beta_4 sch_i + \beta_5 dch_i + \beta_6 ddch_i + \beta_7 mbp_i + \beta_8 rcc_i + \beta_9 dntwof_i + \beta_{10} drtwof_i + \beta_{11} pntwof_i + \beta_{12} prtwof_i + \beta_{13} spc_i + \beta_{14} spf_i + \beta_{15} spcf_i + \beta_{16} nh_{3i} + \beta_{17} bdf_i + \beta_{18} ilf_i + \beta_{19} hw_i + \beta_{20} whtyd_i + \beta_{21} hc_i + \beta_{22} cornyd_i + \beta_{23} hgs_i + \beta_{24} gsyd_i + \beta_{25} hsb_i + \beta_{26} sbyd_i + \beta_{27} hsf_i + \beta_{28} swth_i + \beta_{29} rh_i + \beta_{30} slrb_i + \beta_{31} llrb_i + \beta_{32} lsb_i + \beta_{33} ssb_i + \beta_{34} cs_i + \beta_{35} rm_i + \beta_{36} fpm_i + \beta_{37} gsm_i + (\beta_{38}\beta_1 fcwf_i) + (\beta_{38}\beta_2 swf_i) + (\beta_8\beta_9 dntwf_i) + (\beta_{38}\beta_{10} drtwf_i) + (\beta_{38}\beta_{11} pntwf_i) + (\beta_{38}\beta_{12} prtwf_i)]\{\beta_{39} + \beta_{40} ha_i\} + e_i,$$

where variables in the model are defined in Table 1 and the subscript i denotes individual farms.

The estimated coefficients β_1 to β_{37} represent the per unit charge to perform the respective field operations. The sign on all of the coefficients is expected to be positive, as to say it actually does cost money to perform field operations. The estimated coefficients β_{20},

β_{22}, β_{24}, and β_{26} represent the harvesting cost per bushel for yields above 20, 48, 35, and 24 bu/ac for wheat, corn, grain sorghum, and soybeans, respectively. The "fertilizer operation adjustment percent" coefficient, β_{38}, represents the percent an estimated field operation coefficient must be adjusted to take into account the simultaneous application of fertilizer with that operation. One would expect this to be greater than 1 (100%), signifying that an operation with fertilizer applied will cost more than the same operation without fertilizer applied, due to the additional equipment and attachments needed to apply fertilizer, as well as the reduced field efficiency of applying fertilizer (more time spent filling or switching fertilizer tanks, and less time performing the desired operation). The intercept term of the linear scale factor adjustments (β_{39}) is expected to be positive while the slope term (β_{40}) is expected to be negative. This will allow for the scale factor $(\beta_{39} + \beta_{40} ha_i)$ to decrease as a farm increases harvested acres, resulting in economies of size.

The empirical specification of the quadratic model (model 2) is the same as model 1 except that a term for harvested acres squared (ha^2) is added to the scale adjustment. Model 2 is specified as

$$(3) \qquad tcmc_i = [\bullet]\left\{\beta_{39} + \beta_{40} ha_i + \beta_{41} ha_i^{\,2}\right\} + e_i ,$$

where the bracketed term [•] is the same as that specified in model 1. The signs on the estimated scale coefficients $(\beta_{39}, \beta_{40}, \beta_{41})$ are expected to be positive, negative, and positive, respectively. This will allow for increasing returns to scale at a decreasing rate, an optimal farm size, and ultimately decreasing returns to scale.

Model 3, a reciprocal model, uses one divided by harvested acres (1/ha) to allow an asymptotic scale factor and is specified as

(4) $$tcmc_i = [\bullet]\left\{\beta_{39} + \beta_{40}\left(\frac{1}{ha_i}\right)\right\} + e_i,$$

where the bracketed term [•] is the same as that specified in model 1. Both of the scale parameters $(\beta_{39}$ and $\beta_{40})$ are expected to be positive numbers. This would result in a positive scale factor that decreases at a decreasing rate, i.e., $\left\{\beta_{39} + \beta_{40}\left(\frac{1}{ha_i}\right)\right\}$ asymptotically approaches β_{39} as harvested acres (ha) approaches infinity (Gujarati).

Model 4 uses a logarithmic scale factor to evaluate farm size impacts on the machinery costs for a farm and is specified as

(5) $$tcmc_i = [\bullet]\left\{\beta_{39} + \beta_{40}\ln(ha_i)\right\} + e_i,$$

where the bracketed term [•] is the same as specified in model 1. The scale coefficients (β_{39} and β_{40}) are expected to be positive and negative, respectively. This would result in a reduced scale factor for larger farms, or increasing returns to scale at a diminishing rate.

A non-linear least squares (NLS) method was used to estimate the models, but resulted in numerous illogical estimated coefficients (i.e., negative field operation coefficients). Therefore, an entropy estimation procedure was incorporated in this research to bring in prior information (published custom rates) about the estimated coefficients, as well as to ensure reasonable estimates. Using the entropy framework, a prior, or expected value, and upper and lower bounds are needed for each estimated coefficient and error term. For all operations listed in Kansas Agricultural Statistics (KAS) *Kansas Custom Rates* publication for 2001 (Kansas Agricultural Statistics Service), the prior, upper and lower bounds used were the statewide average, maximum, and minimum reported values, respectively. For operations not reported in the KAS *Kansas Custom Rates* for 2001, priors and bounds for related operations were assigned, or calculated. For the error terms, the expected error is zero, with the bounds being three standard deviations of the dependent variable, total crop machinery costs (tcmc), above and below zero. Based on Chebychev's inequality (Golan, Judge and Miller) three standard deviations around the expected value will capture 89% of the observations.

The prior and bounds for the scale coefficients were estimated by regressing the respective functional form of harvested acres from models 1-4 on ratio R defined below (equation 7). The upper and lower bound for the estimated scale coefficients was determined to be three standard errors above and below the estimated coefficients.

Once the empirical models are estimated, they will be tested out-of-sample using a jackknife procedure, deleting approximately 10% of the observations, re-estimating the model, and then predicting the deleted observations. This process is repeated until all observations have been deleted and the model re-estimated to provide an out-of-sample prediction for all observations (Maddala). The model that predicts the best in an out-of-sample framework is preferred because when producers not included in this dataset apply this research to estimate per acre machinery costs for their own operations, they will be predicting out-of-sample. All four models will be estimated both in-sample and out-of-sample to determine the best model. The correlation coefficient (CC) (between predicted and actual values) and root mean square error (RMSE) will be used to measure the relative predictive accuracy of the models.

Data

This research combines the number of field operations with farm financial data from a sample of Kansas Farm Management Association (KFMA) members. The field operations were obtained from a survey of the individual farms for field operations performed in the year 2001. There were 182 farms in this research, with an average, minimum, and maximum harvested acres of 1,188, 188 and 3,818 respectively. The financial data for the respective farms was obtained from Kansas Management, Analysis and Research 105 (KMAR), which compiles financial and production data for the KFMA members. The total crop machinery cost (tcmc) for each farm was determined by the sum of the crop share of: machinery repairs, gas, fuel, oil, farm auto expense, depreciation, machine hire, machinery insurance, machinery shelter, opportunity interest on crop machinery investment, and crop machinery labor. The crop machinery labor cost includes only crop machinery labor (time dedicated to machinery operation, maintenance, repairs, and management), as compared to total crop labor cost that would include crop machinery labor as well as time spent managing the crop enterprises (i.e., marketing, crop scouting, complying with government programs, etc.).

To better depict how the costs of the farms in this research compare to custom rates, a ratio R was developed to compare state-wide custom rates to a farm's total crop machinery costs. To calculate R, K_i was calculated to be the "expected total crop machinery costs" for farm i, had all operations been performed at state-wide average custom rates, and is defined as

$$K_i = \sum_j \left[\gamma_{ji} \alpha_j \right], \tag{6}$$

where α_j is the state average KAS custom rate for operation j and γ_{ji} is the number of units of operation j performed on farm i. As such, R is defined as

$$R_i = \frac{tcmc_i}{K_i}. \tag{7}$$

A ratio less than one, equal to one, and greater than one would indicate a farm has crop machinery costs less than, equal to, or greater than the state-wide average Kansas custom rates for the respective operations performed on that farm. Across all farms, the ratio R had an average, minimum, maximum, and standard deviation of 1.31, 0.55, 2.47 and 0.40, respectively.

Of the 182 observations, 43 (23.6%) have machinery ownership and operating costs which are less than the custom rates.

Results

All four models were estimated using the entropy procedure in-sample, and then were tested with the jackknife estimation procedure to derive out-of-sample model statistics. Table 2 displays the estimated coefficients from the in-sample models. The KAS state average custom rates, and other calculated priors were included for a reference of how the estimated coefficients relate to the reported priors, and are reported in the KAS column.

From the in-sample model statistics (Table 2) the reciprocal model has the highest CC (0.874) and the lowest RMSE (27,598). The out-of-sample model statistics (Table 3) show that the reciprocal model dominates, with the highest CC (0.869) and the lowest RMSE (28,204). As such, the reciprocal model will be used in the remaining discussion of this research. On average, across operations, the field operation coefficients decreased by 1.4% from the priors (custom rates) for the reciprocal model. Considering this, and the average size Kansas farm in this research (1,188 harvested acres), 25.5% $\left(1.255{=}1.241{+}\left(33.027\frac{1}{\text{harvested acres}}\right)-0.014\right)$ would need to be added to published custom rates to arrive at the true cost to own and operate machinery.

The estimated coefficients reported in Table 2 are the custom rates estimated by these models, and the respective scale adjustment factors to take into account farm size. Two ways to estimate a farm's per unit machinery costs are available. The first option would be to multiply the estimated coefficient for the operation of interest times the scale factor adjustment for the farm taking into account the number of harvested acres of the farm. This results in the expected per unit cost for that farm to perform the desired operation. However, this method does not take into account cost information from the farm.

The second option can be used if the producer wants to predict a more accurate field operation estimate for their operation. It takes into account farm specific information about the number of units on which each operation was performed during a time period (e.g., one year), and the crop machinery costs for that same time period to prorate whole farm machinery costs to a specific operation. The following seven step process will allow a producer to estimate per unit costs of performing field operations based on his or her actual farm costs.

1. Estimate expected per unit machinery costs
2. Estimate expected crop machinery costs for each field operation
3. Estimate expected aggregate crop machinery costs
4. Estimate the field operation percentages
5. Find actual aggregate crop machinery costs
6. Find prorated actual field operation costs
7. Find actual per unit machinery costs

Step one, estimating expected per unit machinery costs, is the same process that is described as the first option of estimating per unit machinery costs. This provides the producer with the expected cost per unit to perform that operation.

Step two, estimating expected crop machinery costs for each field operation, is the product of the estimated expected per unit machinery costs, step one, and the number of units (acres, tons, bales, etc.) on which that operation was performed. This represents the expected cost for the farm to perform the operation of interest during the time period over the number of units that operation was performed.

Step three, estimating expected aggregate crop machinery costs, is the sum of the estimated expected machinery costs for each operation (step two) across all operations. This represents the farm's total expected crop machinery cost.

Step four, estimating the field operation percentages, is the division of the estimated crop machinery cost per operation (step two) by the estimated aggregate crop machinery costs (step three), to determine the percentage of estimated costs each operation makes up of the total estimated crop machinery costs.

Step five, finding actual aggregate crop machinery costs, is where the individual farm's management abilities, cost characteristics, and changes in underlying machinery economics over time, are taken into account. In this step, the farm would sum together the crop portion of market depreciation, farm automobile expense, opportunity charge on the machinery investment, machinery insurance, machinery shelter, repairs, fuel, lubrication, labor, machinery rent, and machinery leasing as well as custom farming performed for the farm. The dollar value of the custom farming performed for others would then be subtracted from this value to yield the total crop machinery costs for the farm. All of these costs are relatively easy to determine if a moderate amount of effort is put into farm financial tracking except for the market depreciation and opportunity interest on machinery investment. Market depreciation can be estimated by evaluating the loss in value of similar machinery in classified ads or area auctions. The opportunity charge on the machinery investment simply represents the revenue foregone for having capital invested in machinery, rather the next best investment. If the farm has only cropping enterprises, then 100% of each of these costs should be used. However, if the farm has livestock, or other enterprises, the expenses will need to be prorated to their respective enterprises. If the individual producer does not keep track how much time each piece of machinery is used and how much labor is devoted to each operation, the producer could estimate the amount of each expense to be allocated to crops, and how much to be allocated to other enterprises. A producer must remember that the labor allocated to crop enterprises must also be prorated between machinery labor, and non-machinery labor related to the crop enterprises. Because a share of labor allocated to crop enterprises is not directly related to operating machinery, such as time spent making management decisions, complying with government programs, crop scouting, etc.

Step six, finding prorated actual field operation costs, is the product of field operation percentages (step four) and the actual aggregate crop machine costs (step five) to determine the prorated actual field operation costs. This represents the farm's prorated cost to perform the respective operation, as compared to the estimated cost to perform the operation, as found in step two.

Step seven, finding actual per unit machinery costs, finds the actual per unit machine costs by dividing the prorated field operation costs (step six) by the number of units that operation was performed over. This is the farm specific cost to perform that particular field operation on a per unit basis. Since it includes the farm's own machinery costs it is not based on averages or assumptions that do not reflect the farm's individual management.

For a farm to determine its relative standing to other farms with respect to machinery ownership and operating costs, it can benchmark its machinery costs. To do this, the farm would calculate a relative crop machine cost coefficient, B, where B is calculated as

$$(8) \qquad B = \frac{\text{actual aggregate crop machine costs (step 5)}}{\text{expected aggregate crop machine costs (step 3)}}.$$

If this relative crop machinery cost coefficient is one, then the farm can perform the operations at the average cost of other producers. If it is greater than one, the farm has relatively higher machinery costs, if it is lower than one, the farm has relatively lower machinery costs.

Conclusions

Machinery costs play a significant role in farm profitability, and is generally the second largest cost category on crop farms, following land cost. Management does play an important part in making a difference in these costs, and managers who tend to have lower costs tend to also have higher profits according to the literature. In managing machine costs, a farm must know its own machine costs. To find one's own machine costs, estimators are present but have limitations of being complicated, time intensive, and inaccurate due to specific management abilities. To compensate for the inadequacies of machinery cost estimators, one may use a market price for performing the different field operations adjusted for individual farm characteristics. Market prices that are updated annually are custom rates, published by Kansas Agricultural Statistics. This research found that custom rates for an average size Kansas farm are 25.5% lower than the true cost to own and operate machinery because of work done for friends, family and neighbors. Therefore, a "true" custom rate (i.e., one that includes total ownership and operating costs) was estimated that can be used to prorate a farm's machinery costs to different field operations. The farm's prorated machinery costs can then be used to benchmark the farm's actual costs against its expected costs, so a farm manager can see the farm's strengths or weaknesses with regards to total machinery costs.

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Table 1. Model Variables and Respective Estimated Coefficients.

Variable	Meaning	Coefficient
tcmc	Total crop machinery cost, dollars	
fcwof	Field cultivation without fertilizer, acres	β_1
swof	Sweep/undercut without fertilizer, acres	β_2
dsk	Disk, acres	β_3
sch	Chisel, less than 12 inches deep, acres	β_4
dch	Chisel, greater than 12 inches deep, acres	β_5
ddch	Disk chisel/disk-deep chisel, acres	β_6
mbp	Moldboard plow, acres	β_7
rcc	Row crop cultivate, acres	β_8
dntwof	No-till drill and/or air-seed without fertilizer, acres	β_9
drtwof	Regular-till drill and/or air-seed without fertilizer, acres	β_{10}
pntwof	No-till plant without fertilizer, acres	β_{11}
prtwof	Regular-till plant without fertilizer, acres	β_{12}
spc	Spray chemical, acres	β_{13}
spf	Spray fertilizer, acres	β_{14}
spcf	Spray chemical and fertilizer, acres	β_{15}
nh3	Anhydrous ammonia application, acres	β_{16}
bdf	Broadcast dry fertilizer, acres	β_{17}
ilf	Inject liquid fertilizer, acres	β_{18}
hw	Harvest wheat, acres	β_{19}
whtyd	Wheat yield above base rate × wheat acres, bushels	β_{20}
hc	Harvest corn, acres	β_{21}
cornyd	Corn yield above base rate × corn acres, bushels	β_{22}
hgs	Harvest grain sorghum, acres	β_{23}
gsyd	Grain sorghum yield above base rate × grain sorghum acres, bushels	β_{24}
hsb	Harvest soybeans, acres	β_{25}
sbyd	Soybean yield above base rate × soybean acres, bushels	β_{26}
hsf	Harvest sunflowers, acres	β_{27}
swth	Swath, acres	β_{28}
rh	Rake hay, acres	β_{29}
slrb	Large round bales below 1,500 pounds, bales	β_{30}
llrb	Large round bales above 1,500 pounds, bales	β_{31}
lsb	Large square bales, bales	β_{32}
ssb	Small square bales, bales	β_{33}
cs	Chop silage, tons	β_{34}
rm	Rotary mow, acres	β_{35}
fpm	Farm pickups and service vehicles, miles	β_{36}
gsm	Trucks hauling grain and hay, miles	β_{37}
	Fertilizer operation adjustment percent	β_{38}
fcwf	Field cultivation with fertilizer, acres	
swf	Sweep/undercut with fertilizer, acres	
dntwf	No-till drill and/or air-seed with fertilizer, acres	

Table 1. Model Variables and Respective Estimated Coefficients (Continued).

Variable	Meaning	Coefficient
drtwf	Regular-till drill and/or air-seed with fertilizer, acres	
pntwf	No-till plant with fertilizer, acres	
prtwf	Regular-till plant with fertilizer, acres	
	Constant	β_{39}
ha	Total harvested acres	β_{40}
e	Error term	

Table 2. Estimated Coefficients for the Four Different Models.

Variable	Unit	Model 1 (Linear)[a]	Model 2 (Quadratic)[a]	Model 3 (Reciprocal)[a]	Model 4 (Logarithmic)[a]	KAS[b]
fcwof	$/acre	5.60	5.66	5.55	5.69	5.92
swof	$/acre	5.42	5.43	5.39	5.43	5.38
dsk	$/acre	6.35	6.43	6.33	6.45	6.48
sch	$/acre	7.88	7.90	7.88	7.90	7.79
dch	$/acre	9.45	9.47	9.42	9.46	9.54
ddch	$/acre	9.27	9.31	9.27	9.30	9.54
mbp	$/acre	8.96	8.97	8.96	8.97	8.98
rcc	$/acre	6.41	6.41	6.40	6.41	6.25
dntwof	$/acre	10.08	10.07	10.03	10.11	9.89
drtwof	$/acre	5.93	5.99	5.88	6.00	6.49
pntwof	$/acre	9.90	9.86	9.79	9.94	10.02
prtwof	$/acre	8.15	8.21	8.11	8.21	8.03
spc	$/acre	3.66	3.69	3.63	3.70	3.75
spf	$/acre	3.73	3.73	3.73	3.73	3.75
spcf	$/acre	3.76	3.75	3.74	3.76	3.75
nh3	$/acre	5.55	5.53	5.50	5.55	5.61
bdf	$/acre	3.42	3.42	3.41	3.43	3.53
ilf	$/acre	3.53	3.51	3.51	3.53	3.57
hw	$/acre	13.78	13.88	13.64	13.93	13.77
whtyd	$/bushel	0.131	0.131	0.130	0.131	0.131
hc	$/acre	20.17	20.28	20.08	20.26	19.43
cornyd	$/bushel	0.126	0.127	0.126	0.127	0.119
hgs	$/acre	14.32	14.23	14.14	14.35	14.58
gsyd	$/bushel	0.128	0.128	0.128	0.128	0.129
hsb	$/acre	19.02	19.16	18.99	19.16	19.48
sbyd	$/bushel	0.127	0.127	0.127	0.127	0.127
hsf	$/acre	18.00	18.00	17.99	18.01	17.93
swth	$/acre	8.35	8.37	8.36	8.38	8.20
rh	$/acre	2.92	2.93	2.93	2.93	2.88
slrb	$/bale	7.34	7.34	7.36	7.36	7.46
llrb	$/bale	7.99	8.02	7.99	8.02	8.15

Table 2. Estimated Coefficients for the Four Different Models (Continued).

Variable	Units	Model 1 (Linear)[a]	Model 2 (Quadratic)[a]	Model 3 (Reciprocal)[a]	Model 4 (Logarithmic)[a]	KAS[b]
lsb	$/bale	12.07	12.07	12.08	12.08	11.70
ssb	$/bale	0.532	0.533	0.533	0.533	0.535
cs	$/ton	3.07	3.07	3.07	3.07	3.09
rm	$/acre	7.83	7.84	7.83	7.84	7.90
fpm	$/mile	0.336	0.341	0.336	0.341	0.345
gsm	$/mile	1.79	1.84	1.80	1.84	2.07
fertilizer	percent	112.5	112.6	112.4	112.6	113.4
fcwf	$/acre	6.30	6.37	6.24	6.41	6.72
swf	$/acre	6.09	6.11	6.06	6.12	6.10
dntwf	$/acre	11.35	11.34	11.28	11.39	11.22
drtwf	$/acre	6.67	6.75	6.61	6.75	7.36
pntwf	$/acre	11.14	11.40	11.00	11.20	11.37
prtwf	$/acre	9.17	9.25	9.11	9.25	9.11
Scale Factors						
constant	--	1.364	1.452	1.241	1.792	--
ha	--	-6.2×10^{-5}	-2.1×10^{-4}	--	--	--
ha^2	--	--	4.3×10^{-8}	--	--	--
1/ha	--	--	--	33.027	--	--
ln(ha)	--	--	--	--	-0.076	--
In-sample Statistics						
CC[c]	--	0.871	0.871	0.874	0.872	--
RMSE[d]	--	27,648	27,688	27,598	27,607	--

[a] Functional form of the scale factor adjustment
[b] Average custom rate reported by Kansas Agricultural Statistics
[c] Correlation coefficient
[d] Root mean square error

Table 3. Out of Sample Model Statistics for the Four Different Models

	Model 1 (Linear)[a]	Model 2 (Quadratic)[a]	Model 3 (Reciprocal)[a]	Model 4 (Logarithmic)[a]
CC[c]	0.864	0.858	0.869	0.865
RMSE[d]	28,368	29,021	28,205	28,353

[a] Functional form of the scale factor adjustment
[c] Correlation coefficient
[d] Root mean square error