Grower Production and Economic Efficiency in the Semi-Arid Southern Great Plains



By Lixia H. Lambert, Hannah E. Shear, and Jason Warren

Lixia H. Lambert is an Assistant Professor in the Department of Agricultural Economics at Oklahoma State University. Hannah E. Shear is an Assistant Professor in the Department of Agricultural Economics at Oklahoma State University. Jason Warren is a Professor in the Department of Plant and Soil Sciences at Oklahoma State University.

Acknowledgments

This research was supported by the Oklahoma Agricultural Experiment Station and the USDA NIFA Hatch Multistate Project W4190 and NC-1177. The views are those of the authors alone.

Abstract

Agricultural production competitions that focus on a single crop, relatively similar field conditions, and similar growing conditions can provide valuable information to extension educators, researchers, and growers on input and resource management. Using data collected from a grower competition in the Oklahoma panhandle, a semi-arid region, we estimated the relative production and economic efficiency scores for competing grower teams. Efficiency was measured using data envelopment analysis (DEA) procedures. Results show that comparatively lower fertilizer application rates and higher rates of irrigation generated the highest efficiency scores. Limited application of fertilizer and irrigation may achieve technical and cost efficiencies, but it is not an optimal decision if the producer's objective is to maximize profit.

INTRODUCTION

Sustainable irrigated agriculture in the Southern Great Plains semi-arid regions depends on how the producers manage scarce water resources and other inputs (Evett et al., 2020; Hansen et al., 2012; Parton, Gutmann, and Ojima, 2007). Agronomic and economic models and extension personnel provide producers with resources to identify when and how much inputs to apply to achieve economically optimal outcomes under different growing and prevailing market conditions. However, agricultural producers may not always make optimal input use decisions based on variability of commodity price, input costs, and yield, and their decision-making criteria varies across geographic locations, crop types, and a changing climate (Patrick et al., 1985).

In an effort to develop effective extension education materials to help agricultural producers make better decisions in semi-arid production regions, it is useful to first understand the farm management decisions currently made by producers. Analyzing producers' real-time decisions and the production and economic consequences will help extension educators and producers learn the impact of different management strategies on input use with respect to the region's growing condition, along with national input costs and output prices. As it has long been known, comparison to a neighbor's operation can lead to better decision-making (Baker, 1971). A well formulated and designed producer contest is expected to provide participants the opportunity to observe the impact of different management decisions and glean some understanding from the choices made by others due to site similarities.

Agricultural production contests with a single crop, relatively similar field conditions, and similar growing conditions can be useful in proving information to producers about their operations and encourage them to identify best resource management practices among their peers (Sheremeta, 2013; Henry et al., 2022). This type of contest has a long history of implementation in the United States, with many commodity organizations hosting annual yield competitions. For example, the National Corn Growers Association hosts the annual national corn yield contest and the National Wheat Foundation has a national wheat yield contest. Although yield is one of the most important engineering and agronomic factors that affect producers' revenue, maximum production does not necessarily (if ever) guarantee maximum profits, given fluctuations in input costs and commodity prices. A competition focused on both profit maximization and production efficiency is more reflective of the production environment while also being more applicable and useful for farm management analyses. Evaluating producer decisions regarding input management decisions in terms of production and economic efficiency could be a potentially compelling indicator to producers as they adjust their management protocol.

This research analyzed data collected from a grower competition in the Oklahoma panhandle region. Details of the competition are discussed along with summary information in the data and methods section. The production and economic efficiency are calculated using data envelopment analysis (DEA) (Chavas and Aliber, 1993; Färe, Grosskopf, and Lovell, 1985; Coelli et al., 2005). This method allows for a relative comparison of the producers with respect to their production and economic efficiencies. The data collected is from the 2019 competition, but further analysis simulating output price distributions was utilized to determine the impact on the producers' economic efficiency under different fertilizer costs.

METHOD AND DATA

2019 Testing Ag Performance Solutions in Oklahoma

Testing Ag Performance Solutions (TAPS) was created in 2017 in Nebraska by a team of researchers at the University of Nebraska–Lincoln's West Central Research, Extension, and Education Center as a sprinkler corn farm management competition. Producers can "win" the TAPS competition in one of three ways: most profitable producer, highest input efficiency, and greatest grain yield. Recognizing the top teams for being the most profitable and the most efficient with input use is what makes this farm management competition more similar to the environment in which producers operate outside of the TAPS competition.

Oklahoma State University's first TAPS annual sprinkler irrigated corn farm management competition was established and conducted in 2019 at the McCaull Research and Demonstration Farm in Eva, Oklahoma. Six farms, a team of university extension specialists, and an Oklahoma State University student team participated in this competition (Table 1). Teams A–F are farmers, Team G is the team of extension specialists, and Team H is a student team. Each team competed for three prize places: first place goes to the most profitable team, second place goes to the team with the highest input efficiency, and third place goes to the team with the greatest corn yield.

Each team was randomly assigned to a set of four experiment-sized plots, totaling about 1.2 acres. Teams made decisions as they would on a real Oklahoma panhandle irrigated corn farm, with control over N fertilizer and irrigation only. University personnel carried out each team's production management decisions. All other management decisions and field maintenance, such as pesticide use and residue management, were fixed and carried out by the same university personnel to ensure uniformity. Although participants were encouraged to observe and monitor their plots, install their own equipment, and/or collect additional data from their plots throughout the growing season at their own expense and risk, they were not permitted to change, modify, alter, or add to any of the competition management protocols. This includes the use of additional inputs of any kind, such as fertilizers, biologics, herbicides, and additives.

Communication between each team and university personnel occurred through the competition website, on which each team's production decisions were tracked. University personnel regularly took photos and collected data for each team and shared the information only with team members. Other photos and ancillary data, including weather, growth stage advancement, and data collected by soil water sensor and aerial photographs, were posted to the website as they were collected and made accessible to all teams.

Data

To calculate the production and economic efficiency, we used data only on irrigation and nitrogen fertilizer management because each team was obligated to decide on these inputs, whereas other inputs and practices such as insurance were deemed optional. The amounts of pre-plant, side-dress, and in-season nitrogen fertilizer are in the forms of UAN 32% as fertigation and anhydrous ammonia 82% for pre-plant and side-dress. Pre-plant nitrogen decisions were submitted by March 10, 2019. Fertigation nitrogen was applied at four vegetation stages: V1 (Stage 1 thereafter), V12 (Stage 2 thereafter), VT/R1 (Stage 3 thereafter), and R2 (Stage 4 thereafter).[1] Maximum application amount for pre-plant and side-dress was 300 pounds per acre and for each fertigation event was 30 pounds per acre (i.e., total possible fertigation amount was 120 pounds per acre). A pre-season soil report was made available on the website by the competition's kickoff in March. Decisions on the amount of fertilizer in pre-plant, side-dress, and fertigation at each stage by each team are presented in Table 2. Teams A–F applied 30–60 pounds of fertilizer for side-dress, whereas Teams G and H did not apply any side-dress. Teams A and D did not apply any pre-plant fertilizer, whereas Teams B, F, G, and H applied more than 100 pounds per acre of pre-plant fertilizer. Most teams applied fertigation in Stages 1–3, except Team B did not apply fertigation in Stage 1 and Teams C and F omitted fertigation in Stage 4 (Table 2). In 2019, the year of competition, the unit cost for UAN 32% was $0.135 per pound and $0.305 per pound for anhydrous ammonia 82% (Table 3). Both fertilizer prices increased dramatically in 2021.

Each team's decision on irrigation application from June to September is presented in Table 4, including irrigation rate in the second half of June (weeks 3–4), the first (weeks 1–2) and second half (weeks 3–4) of July and August, and the first half (weeks 1–2) of September. From June to August, all teams applied irrigation to their crop, with lower amounts in June and increased amounts in July and August. All teams except Team H did not apply irrigation in September. Team A applied the most irrigation water at 17.31 inches, whereas Team C applied the least with 13.74 inches. Cost of irrigation is set to $6 per inch for the competition.

Yield and Commodity Price

The observed corn yield and received corn prices from each team field were recorded (Table 5). Team A had the highest yield (207 bushels per acre) and received the highest price ($4.64 per bushel). Teams A, B, and D had the chance to market their corn at a higher price than other teams. The market price for corn is $3.93 per bushel, which we used for teams that were not able to sign a contract for marketing their product.

We also simulated corn prices following a triangular distribution. Historical corn prices from 1995 to 2019 were inflated using 2019 as base year and detrended to obtain the minimum ($3.63 per bushel), maximum ($6.65 per bushel), and median ($4 per bushel) of the triangular distribution. The histogram of the 1,000 simulated price samples is presented in Figure 1. This simulated price, along with nitrogen prices in 2019, 2020, and 2021, were used to estimate the expected profit efficiency for each team given their input management practices and output levels in 2019. This procedure introduces input and output market uncertainty into the analysis.

Production and Economic Efficiency Ranking Using DEA Approach

We used the DEA approach proposed by Färe, Grosskopf, and Lovell (1985) to measure each team's relative production and economic efficiency. In DEA, an efficiency frontier is benchmarked using observed teams' behavior. Teams that are 100% efficient fall on this frontier, whereas teams that are less than 100% efficient fall below this frontier, with some closer to the frontier than others. A first advantage of the DEA approach is that it does not impose parametric restrictions on the underlying technology (Chavas and Aliber, 1993). A second advantage of this procedure is that a team's performance can be evaluated relative to other teams. The approach proposed by Färe, Grosskopf, and Lovell (1985) allows for the measurement of overall, allocative, purely technical, and scale efficiency. The goal of DEA in this research is to identify the "best" team among all participating teams, given managerial decisions.

Using DEA, we estimated production efficiency by calculating team technical efficiency (TE) scores under variable return to scale (VRS) and constant return to scale (CRS), and we estimated economic efficiency by calculating team cost efficiency (CE) scores and profit efficiency (PE) scores. PE scores are estimated with respect to fertilizer prices from 2019 to 2021 and simulated output prices to incorporate market uncertainty.

The TE score measures the proportional decrease in input quantity necessary to produce the same amount of output (Equation 1), whereas the CE score measures the ratio of minimum costs to observed cost for each team (Equation 2). Given the price on both inputs (fertilizer and irrigation) and output (corn), the PE score measures the ratio of each team's observed profit to the maximum profit (Equation 3). The measures are:

$$\text{TE} = \frac{\text{Optimal Input per Output}}{\text{Observed Input per Output}} \quad (1)$$

$$\text{CE} = \frac{\text{Minimum Cost}}{\text{Observed Cost}} \quad (2)$$

$$\text{PE} = \frac{\text{Observed Profit}}{\text{Maximum Profit}} \quad (3)$$

The efficiency scores, TE and CE, range from 0 to 1. If the score is 1, it means the team reached the highest performance among the competition participants. The PE score is not bound by 0 and 1 because profit level can be negative. These efficiency scores inform us which team is the most efficient and how well other teams are doing relative to the best performed team with respect to productivity, cost, and profit criteria. The procedure of calculating scores for each team can be formulated as a linear optimization problem (Coelli et al., 2005). To analyze the efficiency of the eight teams, we formulated a set of eight linear optimization models. Details of the model formulation for technical, cost, and profit efficiency can be found in Coelli et al. (2005).

RESULTS

Production and Economic Efficiency in 2019

If looking only at the TE score, all teams have achieved their full technical potential under VRS in 2019 (Table 6). Except for Team D, the rest of the teams also reached full technical potential assuming CRS because Team D applied the lowest amount of fertilizer compared to other teams and the second lowest irrigation application during the growing season. Lower input levels also resulted in the lowest corn yield for Team D (87 bushels per acre).

With respect to CE score, only Teams A and D reached full efficiency in 2019 (Table 7). These two teams are among the lowest in fertilizer application, which positioned them to have the lowest costs on input mix if judging efficiency by comparing the measure to the lowest potential input costs with output level held constant. Given the 2019 fertilizer prices, the CE scores of Teams C and E ranked second and third with efficiency scores, 0.997 and 0.912, respectively (Table 7). Team B ranked lowest in this category, because Team B applied the highest amount of fertilizer (200 pounds of nitrogen) during pre-plant and was fourth highest in irrigation (15.22 inches per acre). Although higher levels of fertilizer and irrigation were used by Team B, the 192 bushels per acre of corn produced by Team B was not the highest yield.

Changing fertilizer prices affected rankings in CE scores. Teams A and D were always fully efficient with respect to the input mix that minimized costs from 2019 to 2021 (Table 7). When facing a lower anhydrous ammonia price in 2020, Team C was also fully efficient, and the CE scores of other teams increased as well. In 2021, fertilizer prices increased substantially for both anhydrous ammonia and UAN32 (Table 3), under which the CE scores decreased from 2020 for all teams except A and D.

The PE scores and ranking show that only Team A was fully efficient in terms of maximizing profit, given the 2019 input prices and corn selling price at $4.64 per bushel (Table 6). Team A used the lowest fertilizer application rate and highest amount of irrigation water, and they achieved the highest yield (207 bushels per acre) among all the teams. Team E ranked second in PE scores and its output yield is also second to highest. It is not surprising that Team D has the lowest PE score because of its low output level, although its fertilizer input cost is also the lowest. The lack of irrigation water may have prevented the yield.

Although Team B applied the highest amount of fertilizer during pre-plant period, its yield is not the highest. Lack of irrigation might be the reason. Team B applied much less irrigation compared with Team A except for irrigation during the second half of June. Team E ranked second on profit efficiency, with a score of 0.901. Both Teams E and B have the second highest yield (192 bushels per acre), but Team E applied much less fertilizer during pre-plant. Therefore, Team E has a lower cost than Team B in this regard. Teams G (extension specialist team) and H (student team) ranked fourth and fifth, respectively, with Team G applying more irrigation than Team H. Both teams applied the same amount of fertilizer over pre-plant, side-dress, and fertigation stages.

Expected Profit Efficiency Under Input and Output Price Uncertainty

The expected profit efficiency (EPE) scores under 2019, 2020, and 2021 fertilizer prices and simulated output prices are presented in Table 8. The cost of irrigation is assumed the same in these years at $6 per inch of water applied. The EPE scores reflect the efficiency level of each team when facing exactly the same input and output price uncertainty under the assumption that individual producers are price takers. Results show that Team A achieved full efficiency on EPE across the board, whereas Team D's EPE scores were the lowest. With respect to different fertilizer prices, the EPE ranking was consistent, but the value of scores decreased when fertilizer prices were high in 2021 since fertilizer prices affect the overall profit level. Low input level may result in cost efficiency, but it can hurt the team's profit level. For example, Team D is fully efficient in CE but remains last in EPE. Teams E and B ranked second and third in EPE, but Team B ranked last in CE scores, indicating that Team B can achieve the same profit level with reduced application of fertilizer in pre-plant period.

CONCLUSIONS

Increasing crop productivity and profitability and improving resource use efficiency is the ultimate goal for producers. Producers make decisions based on growing conditions (such as weather information and soil conditions), resources (such as water), market conditions (input and output prices), technology adoption, available tools for uncertainty and risk management, and their personal experience and knowledge in farming. In an effort to help agricultural producers make better production decisions, we used a grower contest to improve our understanding and provide quantitative evaluations on producer input management behaviors, ultimately allowing extension personnel to see the production and economic return gaps between different decision strategies.

This research uses data collected from the Oklahoma State University TAPS program's irrigation corn competition hosted in 2019, where producers competed for maximum profitability and optimal input (irrigation and fertilizer) management. Production and economic efficiency are calculated using the DEA approach. We calculated technical, cost, and profit efficiency scores under each team's received input and output prices, as well as the input prices in 2020–2021 and simulated output prices.

What we learned from the ranking of efficiency scores of this producer competition is that comparatively lower fertilizer application rates and higher use of irrigation produce better efficiency scores. This was especially true for Team A. Among all the teams, Team A was fully efficient in all measures in 2019, with the lowest amount of fertilizer and the highest amount of irrigation water application. This same team also achieved the highest corn yield among all teams in the competition. The combination of inputs and output also sustained Team A under the high fertilizer prices of 2021 and uncertainty in commodity price, to maintain efficiency.

Another finding is that low fertilization and low irrigation could achieve a full score in technical efficiency and cost efficiency, but it will not necessarily be a good option if the producer's objective is to maximize profit level. In this study, Team D used the lowest amount of fertilization and the lowest rate of irrigation. This team's yield was also the lowest among all teams. With respect to cost efficiency, Team D's input-mix was fully efficient across low and high fertilizer prices. However, Team D's profit efficiency in 2019 and expected profit efficiency under uncertain output prices was the lowest among all teams. Team D's profit efficiency rankings also suggest the importance of sufficient irrigation water application during the growing season. Simultaneously decreasing water and fertilizer application could result in lower yields and missed profit targets.

Competition among producers with homogeneous physical growing conditions on soil and weather, as well as production technology, provides an ideal space to observe and evaluate each producer's decision on fertilizer and irrigation applications in Oklahoma's major irrigation agricultural area. Fertilization and irrigation are complementary inputs that are essential to producers in this region, where fertilizer prices have increased and groundwater is diminishing at an alarming rate. The results from the competition show that an optimal mix of these two inputs can increase productivity and producer profit, especially with high irrigation and low fertilization.

The limitations of this research are that (1) we focused only on the uncertainty of fertilizer prices and output prices, although the irrigation cost, especially energy cost, will also increase if the producers must go deeper into the well to withdraw groundwater for future irrigation; and (2) although the study shows the impact of commodity price and input price uncertainty on economic efficiency, more research is required to understand what kind of insurance options are available and how insurance will affect producers' efficiency scores. Future research should also consider different soil types that producers work with in the region.

FOOTNOTE

1. These are corn growth stages. At V1 (Stage 1), the plant is about 2 to 4 inches tall and seed is the plant's main energy source. By V12 (Stage 2), the plant reaches about 4 feet tall or more. Plant growth demand on nutrients and water is very high at this stage. VT/R1 (Stage 3) is a critical period for pollination and kernel development. At R2 (Stage 4), kernels are well formed and embryos are developed. (Source: https://www.dekalbasgrowdeltapine.com/en-us/agronomy/corn-growth-stages-and-gdu-requirements.html.)

REFERENCES

Baker, C.B. 1971. "Historic Evolution of Planning and Decision Models." In *Economic Models and Quantitative Methods for Decisions and Planning in Agriculture,* edited by E. Heady. Ames, IA: Iowa State University Press.

Chavas, J.P., and M. Aliber. 1993. "An Analysis of Economic Efficiency in Agriculture: A Nonparametric Approach." *Journal of Agricultural and Resource Economics* 18 (1): 1–16.

Coelli, T.J., D.S.P. Rao, C.J. O'Donnell, and G.E. Battese. 2005. *An Introduction to Efficiency and Productivity Analysis,* 2nd ed. New York, NY: Springer.

Evett, S.R., P.D. Colaizzi, F.R. Lamm, S.A. O'Shaughnessy, D.M. Heeren, T.J. Trout, W.L. Kranz, and X. Lin. 2020. "Past, Present, and Future of Irrigation on the U.S. Great Plains." *Transactions of the ASABE* 63 (3): 703–729. https://doi.org/10.13031/trans.13620.

Färe, R., S. Grosskopf, and C.A.K. Lovell. 1985. *The Measurement of Efficiency of Production*. Boston, MA: Kluwer-Nijhoff Publishing.

Hansen, N.C., B.L. Allen, R.L. Baumhardt, and D.J. Lyon. 2012. "Research achievements and adoption of no-till, dryland cropping in the semi-arid U.S. Great Plains." *Field Crops Research* 132 (14): 196–203.

Henry, C.G., T. Clark, R. Parker, and J.P. Pimentel. 2022. "Results from Four Years of the University of Arkansas System Division of Agriculture Corn Irrigation Yield Contest." In *Arkansas Corn and Grain Sorghum Research Studies 2021*, edited by V. Ford, J. Kelley, and N. McKinney II. University of Arkansas, Division of Agriculture, Research & Extension. Accessed September 5, 2022. https://scholarworks.uark.edu/cgi/viewcontent.cgi?article=1207&context=aaesser#page=54.

Parton, W.J., M.P. Gutmann, and D. Ojima. 2007. "Long-term Trends in Population, Farm Income, and Crop Production in the Great Plains." *BioScience* 57 (9): 737–747.

Patrick, G.R., P.N. Wilson, P.J. Barry, W.G. Boggess, and D.L. Young. 1985. "Risk Perceptions and Management Responses: Producer-Generated Hypotheses for Risk Modeling." *Journal of Agricultural and Applied Economics* 17 (2): 231–238. https://doi.org/10.1017/S0081305200025243.

Sheremeta, R.M. 2013. "Overbidding and Heterogeneous Behavior in Contest Experiments." In *A Collection of Surveys on Market Experiments*, edited by C.N. Noussair and S. Tucker. Hoboken, NJ: John Wiley & Sons. https://doi.org/10.1002/9781118790700.ch6.

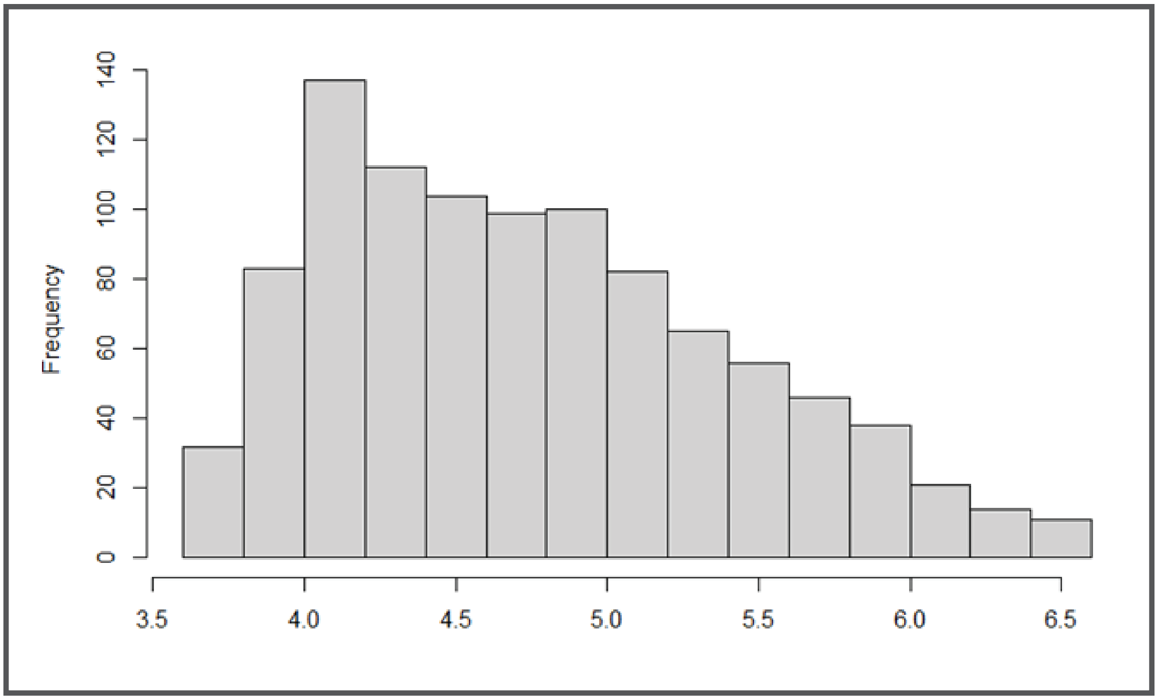

Figure 1. Histogram of simulated corn prices using triangular distribution

Table 1. Teams of Participants

Team	Description
A	Farmers
B	Farmers
C	Farmers
D	Farmers
E	Farmers
F	Farmers
G	Extension specialists
H	Student team

Table 2. Nitrogen Fertilizer Consumption at Different Stage of Production by Each Team (pounds per acre)

Team	Pre-plant	Side-dress	Fertigation				Total
			Stage 1	Stage 2	Stage 3	Stage 4	
A	0	30	30	30	30	30	150
B	200	30	0	0	15	20	265
C	50	50	30	30	30	0	190
D	0	30	30	30	30	30	150
E	50	60	30	30	30	30	230
F	120	30	30	30	30	0	240
G	100	0	30	30	30	30	220
H	100	0	30	30	30	30	220

Table 3. Nitrogen Prices

Item	Price ($/lb)		
	2019	2020	2021
Anhydrous Ammonia 82%	0.305	0.245	0.336
UAN32	0.135	0.138	0.261

Table 4. Each Team's Irrigation Water Application from June to September (inches per acre)

Team	June	July		August		September	Total
	Weeks 3–4	Weeks 1–2	Weeks 3–4	Weeks 1–2	Weeks 3–4	Weeks 1–2	
A	1.10	3.31	4.05	4.05	3.60	1.20	17.31
B	1.27	2.52	3.90	3.98	2.55	1.00	15.22
C	1.00	3.09	4.05	2.80	2.05	0.75	13.74
D	0.65	3.11	3.85	3.80	2.40	0.65	14.46
E	1.00	3.09	4.05	4.10	2.70	0.75	15.69
F	1.27	2.89	3.60	3.75	3.45	0.80	15.76
G	1.02	3.09	4.05	4.10	2.50	1.25	16.01
H	1.02	3.09	4.05	4.10	2.50	0.00	14.76

Table 5. Output Yield and Price Received by Each Team in 2019

Team	Yield (bu/acre)	Price Received ($/bu)
A	207	4.64
B	192	3.99
C	152	3.93
D	87	4.24
E	192	3.93
F	174	3.93
G	187	3.93
H	182	3.93

Table 6. Technical Efficiency (TE) and Profit Efficiency (PE) Under 2019 Input and Output Prices Received by Each Team

Team	TE (CRS)	TE (VRS)	PE (ranking)
A	1	1	1 (1)
B	1	1	0.862 (3)
C	1	1	0.697 (7)
D	0.776	1	0.348 (8)
E	1	1	0.901 (2)
F	1	1	0.778 (6)
G	1	1	0.859 (4)
H	1	1	0.841 (5)

Table 7. Cost Efficiency (CE) Under Different Fertilizer Prices

Team	2019 Fertilizer Prices	2020 Fertilizer Prices	2021 Fertilizer Prices
A	1 (1)	1 (1)	1 (1)
B	0.757 (7)	0.825 (6)	0.807 (7)
C	0.997 (2)	1 (1)	0.997 (2)
D	1 (1)	1 (1)	1 (1)
E	0.912 (3)	0.930 (2)	0.893 (4)
F	0.810 (6)	0.846 (5)	0.835 (6)
G	0.849 (5)	0.885 (4)	0.873 (5)
H	0.891 (4)	0.929 (3)	0.911 (3)

Table 8. Expected Profit Efficiency (EPE) with Simulated Output Prices

Team	2019 Fertilizer Prices	2020 Fertilizer Prices	2021 Fertilizer Prices
A	1 (1)	1 (1)	1 (1)
B	0.873 (3)	0.890 (3)	0.876 (3)
C	0.704 (7)	0.708 (7)	0.697 (7)
D	0.355 (8)	0.355 (8)	0.340 (8)
E	0.905 (2)	0.909 (2)	0.897 (2)
F	0.789 (6)	0.799 (6)	0.785 (6)
G	0.867 (4)	0.875 (4)	0.865 (4)
H	0.848 (5)	0.856 (5)	0.846 (5)