Effect of Silage Quality on Milk Production and Ogallala Aquifer Conservation Potential in the Texas High Plains

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Abstract: Agriculture production plays an integral role in the regional economy. However, the Ogallala Aquifer that supports the intensive irrigated agriculture and livestock operations is waning rapidly, which raises alarm for future sustainability of agriculture in the area. The main objective of the present study is to evaluate the effect of forage quality of corn and sorghum silage on milk yield per ton of silage dry matter. The traditional quantitative analysis and the Data Envelopment Analysis (DEA) are used. The DEA approach takes into account the comparative production efficiency analysis of corn and sorghum silage. The results revealed that there is a 16% more milk yield from corn silage due to better forage quality than sorghum silage. However, it is economically more profitable to feed dairy the sorghum silage. Improvement in crude protein, *in-vitro* true digestibility and starch content of sorghum silage will increase milk production per ton of forage dry matter. Considering both global and local concerns on water scarcity coupled with unpredictable climate changes, it is economically prudent to consider sorghum silage. Education on the true value of sorghum silage to the dairy industry can reduce silage production cost and save more water for future use in the Texas High Plains.

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Abstract:

Agriculture production plays an integral role in the regional economy. However, the Ogallala Aquifer that supports the intensive irrigated agriculture and livestock operations is waning rapidly, which raises alarm for future sustainability of agriculture in the area. The main objective of the present study is to evaluate the effect of forage quality of corn and sorghum silage on milk yield per ton of silage dry matter. The traditional quantitative analysis and the Data Envelopment Analysis (DEA) are used. The DEA approach takes into account the comparative production efficiency analysis of corn and sorghum silage. The results revealed that there is a 16% more milk yield from corn silage due to better forage quality than sorghum silage. However, it is economically more profitable to feed dairy the sorghum silage. Improvement in crude protein, *in-vitro* true digestibility and starch content of sorghum silage will increase milk production per ton of forage dry matter. Considering both global and local concerns on water scarcity coupled with unpredictable climate changes, it is economically prudent to consider sorghum silage. Education on the true value of sorghum silage to the dairy industry can reduce silage production cost and save more water for future use in the Texas High Plains.

Key Words: Silage Forage Quality, Milk Production, Ogallala Aquifer, Texas High Plains, Data Envelopment Analysis

Introduction:

The economy of the Texas High Plains is made up of a variety of agricultural and non-agricultural industry. Agriculture production remains one of the major driving forces of the Texas High Plains economy and played a dominant role in the livelihood of the people (Guerrero and Amosson, 2013). The direct value of agriculture in the Texas High Plains exceeded $5.8

billion during 2008-2011, and agribusiness contributed 53,264 jobs with an annual payroll of $1.1 billion in the same period (Amosson et al., 2012).

Corn silage and sorghum silage play significant role in the sustainability of livestock industries especially the dairy and feedlot. The dairy industry had positively impacted and significantly boosted the economy of the Southern Ogallala Region and the entire Texas High Plains. The total economic impact of the dairy in the Texas High Plains has been estimated to be more than $2.7 billion (Guerrero et al., 2012; Almas et al., 2015).

Dairy and feedlot industries in the Texas High Plains are on the increase. This has resulted in a significant quantity of feed (silage) needed to keep a pace in order to sustain the business. Jordan et al. (2012) reported that the dairy industry in 4 of the top 10 dairy states in the nation (CA, ID, NM, and TX) rely on irrigation to grow the forage crops consumed in the rations fed to their cows. The significance of irrigation to agricultural productivity as far as yield is concerned cannot be overestimated. Irrigation plays essential role in the crop production system of the Texas High Plains, and that it is able to quadruple crop yield compared to dryland farming (Howell, 2001). Ahamadou et al. (2012) also observed that irrigation increases yield by 2 to 7 times compared to non-irrigation and cut down risk by 75 to 90% when risk is defined as a function of the variability in yield.

Traditionally, corn silage has been the dominant feed most dairies prefer and is a major feed component in the dairy ration. However, corn silage is a high-water use crop. Alternative to corn silage is sorghum silage which is a low water use crop. Extension specialists have investigated water use, quality, digestibility, nutritional, and feed conversion features of forage sorghum silage varieties. Results revealed that sorghum silage can be an attractive alternative crop for feedlot and dairy industries because it is able to supply almost equal nutritional value as corn silage and requires about one-third less water than corn silage (Dean et al., 2007).

The primary groundwater source (Ogallala Aquifer) in the Texas High Plains that supports the intensive nature of agriculture is waning rapidly which raises concerns for future sustainability of agriculture production in the area. The less water usage or drought tolerant nature of forage sorghum silage is an advantage to reduce the quantity of water used for production in the Texas High plains. Almas et al. (2015) reported that the decision to switch 30,000 acres from irrigated corn silage, irrigated grain sorghum, and dryland grain sorghum to irrigated sorghum silage will lead to economic benefit amounting to $4.904 million as well as saving 116,373 acre-feet of water.

Research Objective:

The general objective of this study is to evaluate the effect of forage quality of corn and sorghum silage on milk yield per ton of silage dry matter. The specific objective was to predict the effect of forage quality of corn and sorghum silage on milk yield and asses the relationship between forage quality attributes and milk yield in the dairy animals.

Corn Silage and Sorghum Silage Impact on Milk Production:

Silage is one of the key components for dairy ration. Corn silage has been the dominant feed component of dairy animals' diet in the Texas High Plains, although sorghum silage is catching up. Corn silage enhances quality milk production due to high digestibility, ease of handling, and palatability. However, Jordan (2015) found no significant difference in dry matter intake, milk yield or milk composition of corn silage and sorghum silage fed to 48 mid-lactation cows. The study recommended the use of large number of animals to further confirm the results.

The BMR sorghum silage has higher digestibility and able to produce milk in a manner similar to corn silage when fed to dairy cows. Oliver et al. (2004) compared brown midrib-6 and

-18 forage sorghum with conventional sorghum and corn silage in diets of lactating dairy cows. The results revealed that cows fed the bmr-6 sorghum and corn silage had similar milk production. Cows fed conventional sorghum had the lowest milk production, and cows fed the bmr-18 did not show differences in milk production from cows fed the other diets.

The metabolizable energy (ME) available to the animal for heat and maintenance also influence greatly the amount of milk produced by the animal. Hristov et al. (2005) found that ME and protein intake together with other nutrients such as fat and carbohydrates influence milk yield and composition.

Studies have been done to model the responses of dairy cows to the changes in metabolisable energy intake derived from forage to concentrate ratio. One of such studies found that dairy cows show diminishing returns in milk and milk energy output with increasing nutrient supply however, limitations to these kinds of studies are that the models do not take into account other nutrients such as diet composition (Hulme et al., 1986; Woods et al., 2003, 2004) According to Cabrita et al. (2009) milk yield increase in dairy cows that results from their genetic improvement requires the use of large amounts of concentrates that are rich in energy and crude protein (CP) to meet their nutrients requirements.

Weiss and Wyatt (2006) found that milk production for cows fed with BMR was higher than for cows fed with corn silage dual-purpose hybrid (81.4 vs. 77.8 pounds/day). However, because of changes in fat concentration, yield of energy-corrected milk was not affected by treatment. The only interaction observed was increased yield of milk protein when BMR silage was combined with increased supply of metabolisable protein (Weiss and Wyatt, 2006).

Nutritional Qualities of Corn Silage and Sorghum Silage:

Corn and sorghum silage play significant role in the diet of animals in the dairy and feedlot industries. They are often used to supplement both growing and finishing ration. In terms of nutritional and silage quality, corn silage outweighs sorghum silage in feed value. However, some sorghum hybrids have been found to have similar nutritional value to corn (Bean and Marsalis, 2012). Many studies have compared the nutritional value of sorghum silage and corn silage and concluded that the brown midrib (BMR) and some non-BMR varieties of sorghum have qualities similar to corn in term of digestibility (Bean and McCollum, 2006). Rick (1994) reported that forage sorghum silage has 80 to 90% of the energy value of corn silage per unit of dry matter. Brouk and Bean (2012) found *in-vitro* true digestibility (IVTD) for pre-ensiled corn silage to be between 81-83% whereas average value for the normal and BMR types of forage sorghums also had 76% and 81%, respectively.

Dann et al. (2008) did a study that compared brown midrib sorghum-Sudan (bmrSS) grass with corn silage (CS) on lactation performance and nutrient digestibility in Holstein dairy cows. The results revealed that cows fed with bmrSS had greater efficiency of solids-corrected milk production, higher ruminal pH, and greater acetate to propionate ratios than cows fed corn silage. It was concluded that in a short-term study, bmrSS appears to be an effective alternative to the corn silage hybrid when fed at either 35 or 45% of dietary dry matter.

Neal et al. (2008) also found that neutral detergent fibre (NDF) content, neutral detergent fibre digestibility (NDFD), starch content, and starch digestion are major factors that determine nutritional value of corn silage for dairy cattle.

Bean et al. (2003) compared different types of forage sorghum silage for forage quality with respect to crude protein (CP), neutral detergent fiber (NDF), lignin content, and *in vitro* true digestibility (IVTD). Results revealed that BMR sorghum silage had very high *in vitro* true digestibility and low lignin content. The study concluded that BMR sorghum silage will be a better alternative to corn silage for the dairy and feedlot industries. Table 1 displays a summary of the results.

Materials and Methods:

The study focuses on the effect of forage quality of corn and sorghum silage on milk yield per ton of silage dry matter. Data for sorghum silage were obtained from the Texas AgriLife Research Center in Amarillo, Texas from sorghum silage trials 2007 to 2014 whereas corn silage data were obtained from 2009 to 2013 corn silage trials from the State Silage Corn Performance Test at Etter, Texas. The variables for predicting the effect of forage quality of sorghum silage on milk yield per ton of silage dry matter included 240 observations while corn silage variables were 205 observations.

Ordinary least squares (OLS) regression was used to predict the effect of forage quality on milk yield with respect to crude protein (CP), lignin, starch, and *in-vitro* true digestibility (IVTD) of corn silage and sorghum silage. The general specification of the model is given by:

Milk produced = f (forage quality)

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_n X_n + \varepsilon \qquad 1$$

where Y is the milk produced, $X_{1,}$ X_2…………………, X_n represent the explanatory variables of corn silage and sorghum silage forage quality which includes crude protein, lignin, starch, and *in-vitro* true digestibility, ε is the error term, β_0 and β_n are parameters to be estimated. In order to ensure that the independent variables in the regression model are predicting individually and no correlation exists among them, a multicollinearity diagnostic test was conducted. Table 1 presents the results of the multicollinearity diagnostic test on the independent variables.

In order to measure the efficiency analysis of silage quality on milk production, Data Envelopment Analysis (DAE) technique is used. Farrell's (1957) introduced the idea of measuring technical efficiency relative to a production frontier. Charnes et al., (1978) extended this idea towards a multi-factor (multiple inputs and outputs) productivity analysis model. It is called as Data Envelopment analysis. At the start, it considered only a constant return to scale (CRS). Later on, idea of DEA model under variable returns to scale (VRS) was initiated by the Banker et al., (1984).

Constant return to scale (CRS) and variable return to scale (VRS) are two dimensions of the DEA. In case of CRS, it is assumed that if inputs are doubled then output for all institutions can be doubled. Here it is assumed that every university is already operating on the optimal scale. No significant relationship between the scale of operations and efficiency is also assumed. Large universities are considered as efficient as small ones in converting inputs to outputs. (Avkirani, 2001). According to Banker et al. (1984), VRS model compares each DMU only with other DMUs in the same region of return to scale. On the other hand, there are two approaches in order to interpret the DEA such as: input-oriented or output-oriented. Output is considered as fixed and inputs are adjusted to maximize the efficiency under input-orientation. Inputs quantity can be proportionally reduced without a reduction in the output [Al-Bagoury (2013)]. Alternatively, how high maximal output can be achieved with the same amount of resources is the main consideration of the output orientation approach. In conclusion, the output oriented variable return to scale approach is appropriate for present study.

$$
\begin{aligned}
&Max_{\phi,\lambda}\ \phi \\
&St \\
&\qquad -\phi y_i + Y\lambda \geq 0, \\
&\qquad xi - X\lambda \geq 0, \qquad\qquad 2 \\
&\qquad I1'\lambda = 1, \\
&\qquad \lambda \geq 0,
\end{aligned}
$$

Where θ = is a scalar with restriction: θ ≤ 1, λ = is an Nx1 vector of constants, and N1/ λ = 1 represents a convexity constraint which confirms that an inefficient farm is only benchmarked against the farm of similar characteristics. Y symbolizes the output matrix for milk yield. θ represents the total technical efficiency of the i^{th} farms. λ represents Nx1 constants. X represents the input matrix for "N" includes crude protein, lignin, starch, and *in-vitro* true digestibility as the inputs in the present analysis.

Statistical Analysis System (SAS version 9.4) "PROC REG" procedure was used to develop a restricted model for corn silage and sorghum silage forage quality (Crude protein, *In-vitro* digestibility, Starch and Lignin) response to milk yield and DEAP 2.1 procedure was used for milk yield efficiency analysis. The intercept for both silages in the regression models were forced to go through the origin by adding a linear restriction statement (restrict intercept = 0) to the SAS procedure. The model assumed forage quality crude protein (CP), in-vitro true digestibility (IVTD), starch, and lignin content of both silages to be the primary factor that influences milk yield, holding other variables constant. Hence, the intercept been zero implies that absence of the aforementioned forage quality leads to no milk yield.

Results and Discussion:

The results of the study revealed that there is a statistically significant relationship between the forage quality (CP, IVTD24, lignin, and starch) and the amount of milk produced per ton of forage dry matter. The coefficient of determination of the restricted model for corn silage was significant at both 0.01 and 0.05 alpha level with R^2 value of 0.999. The implication is that 99.9% of the variation in milk yield per ton of forage dry matter is explained by the forage attributes.

Crude protein had a statistically significant relationship with milk produced per ton of forage dry matter of corn silage at p-value of 0.0001. The estimate for crude protein was found to be 42.09. The value (42.09) implies that a unit increase in crude protein of the forage quality of corn silage will increase the amount of milk produced per ton of forage dry matter by 42.09 pounds holding other variables constant. Additionally, IVTD24 also had a positive relationship with milk produced per ton of forage dry mater at 1% significant level. The estimate for IVTD24 was 49.78. This means that a unit increase in IVTD24 will increase the amount of milk yield per ton of forage dry matter by 49.78 pounds holding other variables constant. IVTD measures digestibility and can be used to estimate energy. A higher value of IVTD presents a better forage quality which enhances milk production.

Lignin and starch had a negative significant relationship with the amount of milk produced per ton of forage dry matter at p-value of 0.0001. The estimate for lignin and starch were -187.73 and -15.66 respectively. The implication for these estimates are that a unit increase in lignin and starch will decrease the amount of milk produced per ton of dry matter by 187.73 and 15.66 pounds respectively holding other variables constant. Lignin is the primary chemical factor limiting cell wall digestibility; therefore, too much of it in the forage cannot be digested by the animal (Oliver et al., 2004). Also too much starch in the rumen of the animal causes ruminal acidosis (occurs when the pH of the rumen falls to less than 5.5) and depresses ruminal digestion which results in poor digestion and milk production as well as low feed efficiency (Neal et al., 2008). The inverse relation of lignin and starch to milk produced, provide an indication that the present level of lignin and starch in corn silage are enough to enhance milk production.

For sorghum silage the coefficient of determination of the restricted model was significant at both 0.01 and 0.05 alpha level with R^2 value of 0.984. The implication is that 98.4% of the variation in milk produced per ton of forage dry matter is explained by sorghum silage forage quality. Crude protein had a positive significant relationship with milk produced per ton of forage dry matter of sorghum silage at 5% significance level. The estimate for crude protein, which is approximately 45.18, implies that a unit increase in crude protein of sorghum silage forage quality will increase the amount of milk produce per ton of dry matter by 45.18 pounds holding any other variable constant.

In-vitro true digestibility after 48 hours of incubation in rumen fluid (IVTD48) also had a statistically significant positive relationship with milk produced per ton of forage dry mater at p-value of 0.0001 with an estimate value of approximately 25.67. This implies that a unit increase in IVTD48 of sorghum silage forage quality will increase the amount of milk produce per ton of forage dry matter by 25.67 pounds. Starch had a positive significant relationship with the amount of milk produced per ton of forage dry matter at 1% alpha level. The estimate for starch was 16.69 which implies that a unit increase in starch of the forage quality of sorghum silage will increase the amount of milk produced per ton of forage dry matter by 16.69 pounds when other variable are held constant. The lignin content of sorghum silage was not significant. This means that lignin does not have effect on milk yield of sorghum silage. Table 2 displays a summary of the regression analysis for corn and sorghum silage forage quality on milk yield per ton of forage dry matter.

Milk yield analysis of corn and sorghum silage:

The milk yield with respect to crude protein, *in-vitro* true digestibility, starch, and lignin content of corn silage and sorghum silage were calculated using the mean values and the parameter estimates from the regression analysis (Table 3). The lignin component of sorghum silage was not used in the sorghum silage milk prediction because it was not significant in the regression model.

Corn silage milk prediction:

Milk = 42.09 (Crude protein) + 49.78 (IVTD24) -15.66 (Starch) -187.73(lignin)

= 42.09 (8.18) + 49.77 (77.87) -15.66 (37.15) -187.73(3.41)

= 344.30 + 3875.59 - 581.77- 640.16

= 2,998 pounds per ton of silage dry matter

The predicted milk from the corn silage forage quality as far as crude protein, *in-vitro* true digestibility, starch, and lignin content of the silage are concerned is 2,998 pounds (liquid) per ton of silage dry matter, when all other variables are held constant.

Sorghum silage milk prediction:

Milk = 45.18 (Crude protein) + 25.67 (IVTD48) + 16.69 (Starch)

= 45.18 (7.58) + 25.67 (77.45) + 16.69 (15.40)

= 342.46 + 1988.14 + 257.03

= 2,588 pounds per ton of silage dry matter

For sorghum silage, the predicted milk with respect to crude protein, *in-vitro* true digestibility, and starch, content of the silage is 2,588 pounds (liquid) per ton of silage dry matter, when all other variables remain the same. From the two milk prediction equations, corn silage milk produced is more than sorghum silage. There is approximately16% increase in corn silage milk yield more than sorghum silage. However, the cost of corn silage is higher than sorghum silage per ton.

According to Rick (1994) the ratio of corn silage to sorghum silage on dry matter basis is 1: 1.11 for same energy. Considering the corn silage and sorghum silage components in the feed mix of a dairy cow, a total of 12.92 tons of corn silage will be needed in the feed mix per year while 14.35 tons of sorghum silage will be required when replacing corn silage with sorghum silage. For a given number of 45 dairy cows, a total of 581 tons of corn silage will be needed as part of the feed component in the ration formulation to feed the cows per year. At a given price of $48/ton, the cost of 581 tons of corn silage required to formulate a ration for 45 dairy animals will be $27,907. If the number of cows are increased from 45 to 135, a total of 1,744 tons of corn silage will be required at a cost of $83,722. The cost of corn silage increases as the number of cows' increases as well as the quantity of corn silage required.

For sorghum silage, a total of 646 tons will be required to formulate ration for 45 dairy animals in a year. At a given price of $43/ton of sorghum silage, a cost of $27,767 will be incurred for feeding 646 tons of sorghum silage per year. For a given number of 135 dairy animals, the farmer will require 1,937 tons of sorghum silage in a year to feed the animals at a cost of $83,302. The feed cost increases as the quantity of sorghum silage and the number of dairy animals increases. It can be deduced from the feed cost that at the same number of animals and silage requirement, farmers will spend relatively less on sorghum silage feed cost per year.

At a given price of $4/Mcf of natural gas, a total of 430.37 inches of water will be needed to grow 581 tons of corn silage to feed 45 dairy animals at irrigation cost of $1,721 per year whereas for sorghum silage, a total of 399.88 inches of irrigation water will be required to grow 646 tons of the silage to meet the dietary requirement of 45 dairy animals at irrigation energy cost of $1,600 per year.

Milk Yield Technical Efficiency Analysis:

The technical efficiency analysis of forage quality of corn and sorghum silage for milk production is shown in figure 1 and figure 2. The average efficiency in case of forage quality of corn in milk production is around 0.87. The efficiency analysis demonstrates that inputs (CP, IVTD24, lignin, and starch) increased the amount of forage quality of corn silage would subsequently increase the amount of milk production per ton of dry matter by 87 percent. Hence, keeping the inputs, same, 13 percent of milk production per ton can be increased. The regression analysis shown that the increased use of lignin and starch negatively influenced on the milk yield. By appropriate application of inputs the farms of the study area would be able to enhance the milk production at the maximum level of milk production frontier.

Average technical efficiency, in case of forage quality of sorghum silage for milk production is about 0.84. the regression analysis shown that increased use of lignin negatively impacts the milk yield. Hence, balanced use of inputs is required to attain the maximum level of milk yield.

The technical efficiency of sorghum silage is lower than the corn silage for milk production. It is due to the fact the introduction of sorghum silage compared to corn silage is relatively innovative. Most of the farms have the technical efficiency in the range of 0.70 to 80 and above 0.90 in corn and sorghum silage for milk production. Hence, with time, with the introduction of improved sorghum hybrid seed varieties and improved farm practices will be yielding in augmentation of technical efficiency of sorghum silage on milk quality and yield. Breeding of superior varieties and improvement in agronomic practices are the main factors to enhance the grain yield. If breeding and agronomy will work together, it can increase productivity. However, this synergy is often ignored. Grain yield can be enhanced by applying the genetic improvement in water productivity. Here water productivity is defined as the ‘more crop per drop’. Better management practices can increase the capacity of crops to capture water. Large gap between actual and attainable yield per unit of water can be decreased by the agronomic solutions. Genetic and agronomic solutions are related to each other and it can help to narrow the gap between actual and potential yield per unit water use. Investment in genetic and agronomic solutions is the most effective investment in case of scarce research and development funds. It will be beneficial for small farmers. In order to close the gap, efforts towards education and policy development are required. Adoption of such practices will be fruitful.

Conclusion:

The restricted models showed a significant relationship between corn silage and sorghum silage forage quality on milk yield per ton of silage dry matter. Crude protein, *in-vitro* true digestibility, starch, and lignin content of corn silage forage quality explained 99% of the variation in milk yield while sorghum silage forage quality explained 98%. Although there is 16% increase in milk yield in favor of corn silage due to forage quality, it is economically profitable to feed the dairy cows with sorghum silage as far as buying or growing both silages to formulate ration for dairy cows are concerned.

Considering global concerns on water scarcity coupled with unpredictable climate changes, it is economically prudent to consider sorghum silage. Education on the true value of sorghum silage to the dairy industry can reduce silage production cost and save more water for future use especially in the Texas High Plains where the groundwater (Ogallala Aquifer) is waning.

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Table 1: Comparison of sorghum types for forage quality

Types of sorghum	% CP	% NDF	% lignin	% IVTD
Dual Purpose Silage	6.60	46.15	4.35	75.33
Normal Silage	7.45	44.57	4.38	76.93
BMR Silage	7.41	44.91	3.34	80.00
Normal PS Silage	5.27	59.63	5.01	70.22
BMR PS Silage	5.86	56.96	4.01	75.33

Source: Bean et al. (2003)

Table 2: Result showing restricted regression model relating forage quality of corn and sorghum silage to milk yield per ton of forage dry matter.

	Corn Silage Model			**Sorghum Silage Model**		
Explanatory Variables	Estimate	Standard Error	p-Value	Estimate	Standard Error	p-Value
CP	42.086	7.552	0.0001	45.179	20.480	0.0283
IVTD24	49.772	1.397	0.0001	25.668	1.948	0.0001
Starch	-15.656	1.450	0.0001	16.690	3.372	0.0001
Lignin	-187.73	11.318	0.0001	-6.060	7.460	0.4170
R^2	0.999			0.984		
Adjusted R^2	0.999			0.983		

Table 3: Explanatory variables, mean and parameter estimates for corn silage and sorghum silage

Corn silage			**Sorghum silage**		
Variables	Mean	Estimate	Variables	Mean	Estimate
Crude protein	8.18	42.086	Crude protein	7.58	45.179
IVTD24	77.87	49.772	IVTD48	77.45	25.668
Starch	37.15	-15.656	Starch	15.45	16.690
Lignin	3.41	-187.730	Lignin	4.31	-6.060

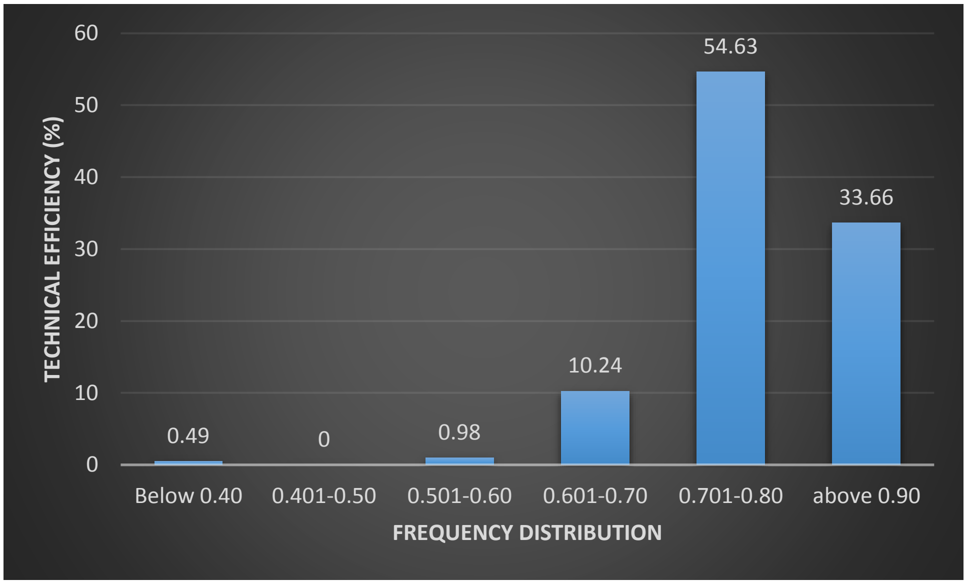

Figure 1. Technical Efficiency Analysis of Corn Silage

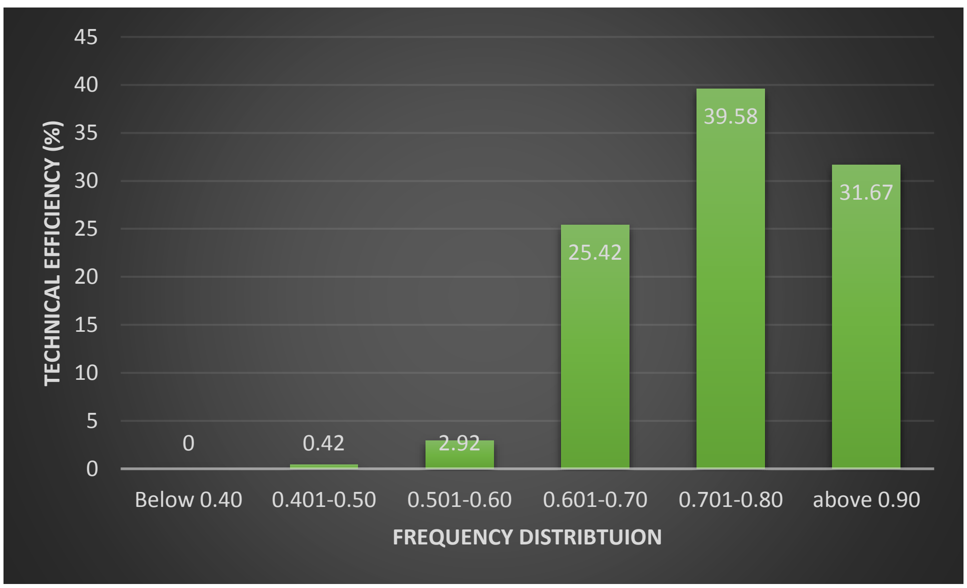

Figure 2. Technical Efficiency Analysis of Sorghum Silage