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Can sorghum Sudanense be an alternative for maize forage in the frame of sustainable water management?

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Abstract
Maize forage is an important feed crop for animal breeding, and it needs a significant amount of water during cultivation. Sorghum Sudanense (Sudan grass) has appeared as an alternative to maize forage with its similar feeding qualities but lower water demand. This study intended to understand the potential effect of de-coupled price supports on production of sorghum and maize. Therefore, production amount of maize and sorghum were estimated for the USA, as a major forage crop producer, with supply response modelling for 1991 and 2021 to understand the effect of price on supplies.
The findings inferred that price affects maize and sorghum supplies in the USA by 20 % on average with an annual lag, with almost no difference. The USA example emphasized the importance of informing producers and sellers of feed products, and animal breeders regarding the low water demand and lower irrigation costs of Sudan grass. This may contribute to lower water use in feed production for animal breeding and to water sustainability accordingly. Besides, it was understood that price incentives may be used to encourage users of sorghum Sudanense rather than sorghum farmers to promote the product in the forage crop market in an indirect way. JEL Codes: Q11, Q18, Q31

Key words
Forage crops, water, sustainability, price, USA

Introduction
Rising population and consumption exert pressure on water, food, energy, and other natural resources. Sustainable and proper utilization of natural resources is very important in meeting the needs of the rising population. Management of resources to proceed in environmental sustainability was emphasized by the United Nations' World Commission on Environment and Development (or the Brundtland Commission after 1983) (Smardon, 2015). Production of goods and services needs to be planned and maintained considering environmental and economic sustainability. This view includes the maintenance of agricultural activities and food production through managing their environmental effects. Due to rising population, demand for vegetable and animal products has been rising. Demand for forage crops that are used as feed in livestock breeding rises as well. However, the amount of water used, especially in roughage production, is quite high. This is an important problem in terms of the sustainability of water supplies.
Water has received more attention recently as an agricultural input as most of the water is concentrated in specific regions (Pimentel et al.,1999; Qadir et al., 2003). In addition to human use for drinking and sanitation, the amount of water used in forage crops is quite high (Huang et al., 2020). The quantity and quality of forage produced are now thought to be important for the efficient use of land. The ability to produce a high dry matter yield of good-quality forage using corn has a stimulating effect on its extensive cultivation, mainly in temperate areas (Wedin, 1970; Silva, 1981).
Forage maize, which is a C4 plant, is important in feeding livestock and it has a significant irrigation water demand. Maize is the least resistant cereal to abiotic stresses such as drought, salinity, and elevated temperatures (Dragičević et al., 2016). Rain-fed maize cultivation is still the most widespread cropping practice. Therefore, water management is very important in forage maize (*Zea mays L.*) production in two sustainability directions. Assuring water supply security and sustainability in cattle breeding is related to the production and use of forage maize. Finding alternatives for forage maize may also contribute to water sustainability.
Sorghum Sudanense, is a high yielding hybrid of sorghum that grows fast and can be adapted to warm conditions as it is drought tolerant (Ha, 1995). Sorghum Sudan grass farming provides a year-round supply of nutritious forage for livestock consumption (Nazli et al., 2014; Chaudhuri et al., 1986). It is widely used in livestock breeding as both green fodder and silage due to its nutrient content and low water requirements (Moray and Istanbulluoglu, 2022). Sorghum has been recognized as a viable option in Europe for addressing these challenges (Ramos et al., 2012). Therefore, it can be considered an alternative to forage maize.
With this research it was aimed to compare these two specific forage crops, forage maize and sorghum Sudan grass. The probability of offering sorghum as an alternative feed was evaluated with a complementary perspective. The price impact on maize and sorghum supplies in the USA was estimated using a time series approach. The selection of the USA was related to its supremacy as a major supplier of both crops.

Materials and methods
The supply response to specific factors, especially price, was estimated for the USA's maize and sorghum production to understand the substitution potential of these two forage crops. The USA was selected as the example for analysis due to the country's experience with both products. Annual change in the USA was demonstrated and evaluated between 1961 and 2021. Following this process, maize and sorghum supplies were estimated for 30 years between 1991 and 2021 using time series supply response analysis (Nerlove and Addison, 1958; Granger 1981). The data was withdrawn from the FAOSTAT databases (Anonymous, 2023).
The main objective of the analysis was to measure the effects of price and non-price factors on the quantity supplied of any product. An important significance of modelling agricultural production is the need to consider time lags, especially for the impact of price. As there is a time gap between the planting and harvest of vegetable products, all factors affect supplies with time differences in the time series analysis frame (Engle and Granger, 1987; Dickey and Fuller, 1981). This process is related to the production characteristics of agricultural products. The exemplary products focused on are annual and accordingly, the supply relationship is expected to involve at least one year of lag, and the statistical equations to be estimated are set as follows:

$$Q_t = f(Q_{t-1}, P_{t-1}, Z_{t-1})$$

Here the quantity produced at time t (Q_t) is estimated against price (P_t) and non-price (Z_t) factors. The main non-price factor was the area in which either maize or sorghum was harvested. Supply of two products were estimated against price and land devoted for cultivation in the USA for 1991–2021 using E-views. The findings were demonstrated in the following section.

Findings
Changing sorghum and maize production in the world and in the USA (1961–2021)
The aggregate lands devoted to maize forage were 105 million hectares in 1961 and had risen to 205 million hectares with 95% coverage in 2021 FAO (Anonymous, 2023). The changing amount produced globally is more significant. The rise was almost five times larger, from 205 million metric tons in 1961 to 1,2 billion metric tons in 2021. For sorghum production, the inference needs further explanation. The amount of land utilized has declined in the past 60 years with 46 million hectares in 1961 reducing to 41 million hectares. However, the global sorghum production was 41 million metric tons in 1961 and rose to 61 million metric tons in 2021. Therefore, a yield appreciation might be considered for sorghum.
The important sorghum producer countries were the USA and Mexico,

followed by Nigeria, Sudan, India, and Ethiopia. The highest amount of production was in 1985, with 77.5 million metric tons. As the crop is annual, the fluctuations are related to weather conditions and the record-keeping of the relevant countries.

Following this global assessment, it was intended to maintain a continental comparison for forage crops. The cultivation land and production amount of two crops were compared between and among two continents: Africa and the Americas for 1961 and 2021. The irrigation characteristics of destinations are the main reason for continental limitations.

The amount of land used for maize production had risen by 175% in 60 years in Africa. Yet, the amount cultivated had risen by almost five times and reached almost 100 million metric tons. The same figures indicated in Table 1 correspond to 113% for land and 146% for the amount produced for sorghum. The yield per hectare more than doubled for maize in the selected years. However, the average yield seemed to be steady for sorghum. This may be attributed to increasing irrigation opportunities in Africa when the rise in maize is considered.

The figures were visited for America as a continent. The change in figures signified rising land and harvested amounts for both crops within 60 years as demonstrated in Table 2. However, there was a fluctuating tendency for sorghum in contrast to maize. The land used for maize forage rose by 75%, the amount cultivated quadrupled and the yield per hectare increased from 2,68 to 7,81 metric tons in 60 years. Despite declining area from 2000 to 2021, there was no reduction in the sorghum production. Due to declining lands and increasing production, the yield seemed to rise during this period. This is also related to irrigation opportunities.

Following the aggregate evaluation, the data for the USA was investigated and evaluated. The land devoted to maize production in the USA rose by 48% from 23 to 34 million hectares in 60 years. The corresponding change in the amount was more than three times higher, from 91 million to 384 million metric tons. A fluctuation in maize yield was observed thereafter. However, the tendency was toward appreciating figures. The highest yield of 11,74 metric tons per hectare was observed in 2016. There was a sharp decline in 2012 to 7,73 metric tons per hectare, which can be related to lower record keeping due to the global crisis and climatic fluctuations.

There were similar fluctuations in sorghum production. The steady rise is being maintained. Yet, the lowest observation in the recent 20 years was in 2012, like for maize. The same reasoning is relevant here as for economic and climatic shifts. In the last 20 years, the yield has seemed to rise by around 30%. The yield change was from 2,74 tons in 1961 to 4,33 tons per hectare in 2021.

These figures signify the need to analyze, especially, the price impact on production of these two alternatives. The analysis was based on a time-series approach, and price was considered the main determinant of supplies. After descriptive and integrative tests, the relationship between two products was reduced to quantity and price.

Sorghum supplies in the USA (1991 – 2021)

The normality of variables was assured via logarithmic transformation, and cointegration processes were confirmed via ADF test procedures (Johansen, 1988). The estimation outputs were demonstrated in Table 3 after confirmation of cointegrating relationships, as all variables were found as I(1) after normalization (Benoit, 2011). Considering the annual characteristics of crops, this has also been an expected situation.

The relationship between sorghum supplies, previous supplies and prices adopted by farmers was estimated. The one-year-lag in supply determinants seemed to explain 32% of the variation in sorghum supplies. This might be considered low, but above 20% significance can be inferred, especially when the joint significance is confirmed with the F-statistic (Table 3). The variation explained by the model is 61%.

It was noted that the parameter estimates in the log-log model indicate percentage changes in the dependent variable (Benoit, 2011; Dickey and Fuller, 1981). So, with a 100% rise in the previous year's sorghum supplies, contemporary supplies rose by 59%. The price impact was lower than the quantity impact. The price dependency seemed to be 4%.

Yet, for proper interpretation, the time effect was checked and demonstrated in Table 4. With the implication of the same procedure, it was understood that the factorial explanation declined slightly to 55%. Yet, the effect of time was negative with 2%, while the previous price level seemed to lead to 22% appreciation.

As the estimation findings are more concise and inferable, the almost negligible time effect could be accepted. This effect can be related to the low acceptance of sorghum by producers or the ease of shifting to other products. Maize supplies were estimated afterwards.

Maize supplies in the USA (1991 – 2021)

The relationship for maize supplies was compared with previous supplies and prices adopted by farmers. The variation explained by the previous production and maize prices appeared to be 61%, and estimates were significant jointly and individually as demonstrated in Table 5.

It was understood that with a 100% rise in the previous year's announced purchasing prices, current maize supplies are expected to rise by 21%. The follow-up effect of the quantity supplied was 54%.

Specifically, the price impact for both forage crops seems to be similar at 20%. Yet, the ease of leaving sorghum production and additional suggestions should be considered with respect to water management in forage crop production.

Results and Discussion

It is essential to look at the water demand of the two crops during irrigation and cultivation. There are many studies that focus on the comparison of forage crops and conclude the superiority of sorghum Sudan grass as an alternative. Some of the relevant studies were summarized below.

Meeske and Basson (1995) studied maize (*Senkuil*) and a forage sorghum hybrid (*DeKalb FS2*) as silage crops under drought conditions. Sorghum yielded more digestible organic matter per hectare than maize, even though their preservation under aerobic conditions was similar.

Huang et al. (2020) studied yields and soil water consumption characteristics of sweet sorghum (*Sorghum dochna*), Sudan grass (*Sorghum Sudanense*), and forage maize (*Zea mays L.*) for two consecutive years under natural rainfall conditions. Forage sorghum presented the highest yield, seemed to consume less soil water than forage maize, in addition to having similar nutritional quality for breeding. Sorghum appeared as an advisable option for forage production in the soil-water-limited semi-arid regions.

Getachew et al. (2016) indicated the adaptation potential of sorghum to a variety of agronomic and environmental conditions, particularly in areas with low rainfall or limited access to irrigation water. Forage sorghum produces a comparable yield to corn, suggesting that there is a potential for sorghum to replace corn in areas where water supply is limited. But there is a lack of information on the feeding value of sorghum silage for high-producing dairy cows.

Uzun et al. (2017) studied changes in irrigation water use efficiency (IWUE) and some agronomic and nutritional characteristics of forage maize and sorghum cultivars (CVs) irrigated in shallow soil. Two maize and seven sorghum cultivars were evaluated in rain-fed (NIR) and irrigated (IR) field conditions for a 3-years period. There was an advantage for sorghum CVs over maize CVs. The superiority of sorghum cultivars was related to agronomic and nutritional traits in shallow soil, irrespective of irrigation.

Schittenhelm and Schroetter (2013) compared the drought tolerance of maize, sweet sorghum, and sorghum Sudan grass hybrids. Sweet sorghum and sorghum Sudan grass hybrids were considered worthy alternatives to maize for biogas production under drought conditions as well.

Piccinni et al. (2009) reported crop water use for maize and sorghum for 3 years. Accumulated seasonal crop water use ranged between 441 and 641 mm for maize and between 491 and 533 mm for sorghum, signing lower average for sorghum.

Gelley et al. (2020) found out that it is essential to prepare agricultural producers for volatile weather changes, specifically drought. This preparation requires a better understanding of forage water use efficiency. Sorghum Sudan grass had appeared as a forage alternative with its drought mitigation and resilience properties.

The relevant previous research can also be related to water preservation potential via cultivating and using sorghum forage. Therefore, the suggestions regarding forage crop preferences should be related to the findings of current research.

Conclusion and Suggestions

Departing from these examples, it was considered beneficial to return the estimation findings for the USA. Sorghum Sudan grass, and maize forage have similar price impacts based on data from 1991 and 2021. The previous year's price affects current supplies of both products by around 20%. Doubling the market price or price incentives may induce a 20% rise in supplies on average. Departing from the USA's example, this can be generalized to countries with similar endowments. However, we need to keep in mind that producers may prefer or focus on either product, but forage maize production is widespread around the world. Yet, introducing or promoting cultivation of the alternative sorghum varieties may contribute to better management of water resources. In this respect, other features of sorghum production should be considered.

Annual preference towards sorghum cultivation seemed to be negative via the estimate of the trend parameter, even if it is very low. This is related to the easy shift to other products, as mentioned before. However, keeping similar price effects aside, the producers may leave sorghum production due to low market awareness or limited demand from cattle breeders, forage sellers, and exporters. If this has been the case for the US market, it is also valid for the rest of the world.

Extensive information of feed farmers and sellers and cattle breeders may increase attention to sorghum farming. Especially if feed farmers are acknowledged about the lower water demand of sorghum farming which leads to lower irrigation costs, they may be willing to shift to sorghum. Consequently, less water use in sorghum farming would contribute to water sustainability or even water security. But to keep farmers in the market, demand from the market needs to be induced. Informing livestock breeders about lower water demand and potential lower costs may lead to change in traditional breeding practices. Direct promotion and information of actors that may use sorghum as feed can contribute to acceptance of sorghum, especially in Asian, American, and African countries, where the costs of animal breeding to the environment and climate have been rising.

These shifts can be achieved via price support or well-calculated subsidies that can be provided by the central or regional authorities. Departing from the US example, it is more achievable and efficient to provide decoupled support where rising yields have not been directly related to the field of production. However, for producers in African countries, where maize production has been declining already due to irrigation causes, cost-price promotions can be considered as more attached to lands or production amounts. Even though the effect of price seems similar with maize, cost efficiency and water savings may lead to changes in the market. Besides, extension activities need to be incorporated into the promotion of the alternative regardless of the existing choice of production. These information efforts should include animal breeders also. Looking at the limited price effect, demand-driven supports may also lead pragmatic changes in favor of producers and environmental sustainability. Even though the effect of price seems similar with maize, cost efficiency and water savings may lead to changes in the market.6.

Tables

Table 1. Land and production amounts of maize and sorghum in Africa

Africa	Maize (corn)			Sorghum		
	area - ha	**tons**	**yield**	**area - ha**	**tons**	**yield**
1961	15.461.095	16.147.243	1,04	13.214.290	10.691.514	0,81
2000	24.248.256	43.798.254	1,81	21.195.363	18.365.958	0,87
2021	42.456.666	96.637.314	2,28	28.134.341	26.280.475	0,93

Table 2. Land and production amounts of maize and sorghum in America

America	Maize (corn)			Sorghum		
	area - ha	**tons**	**yield**	**area - ha**	**tons**	**yield**
1961	43.418.705	116.312.914	2,68	5.799.547	14.390.682	2,48
2000	57.303.735	335.431.253	5,85	7.086.810	23.257.680	3,28
2021	75.860.140	592.356.330	7,81	6.324.741	23.598.501	3,73

Table 3. Sorghum Supply Response

Variable	Estimate	t-statistic (p-value)
Constant	6,36	1,36 (0,18)
Log(Qt-1)	0,59	2,78 (0,01)
Log(Pt-1)	0,04	0,22 (0,82)
R2: 32 %	**Mean Dependent Variable:** 16,23	
F (p-value): 6,26 (0,01)		

Table 4. Sorghum Supply Response with Trend

Variable	Estimate	t-statistic (p-value)
Constant	7,33	1,68 (0,10)
Log(Qt-1)	0,44	2,13 (0,03)
Log(Pt-1)	0,22	1,94 (0,18)
Trend	-0,02	-2,25 (0,03)
R2: 43 %	**Mean Dependent Variable:** 16,23	
F (p-value): 6,50 (0,00)		

Table 5. Maize Supply Response

Variable	Estimate	t-statistic (p-value)
Constant	8,05	3,26 (0,00)
Log(Qt-1)	0,54	3,93 (0,00)
Log(Pt-1)	0,21	2,24 (0,02)
R2: 61 %	**Mean Dependent Variable:** 19,47	
F (p-value): 21,22 (0,00)		

Statement of Conflict of Interest

The author(s) declare no conflict of interest for this study.

Author's Contributions

The contribution of the authors is equal

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