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# Potential Forage Hybrid Markets for Enhancing Sustainability and Food Security in East Africa

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**Abstract:** The cattle sector is strategic sector for both the economic development and food security of Africa. However, the low availability and quality of forage puts the most vulnerable population in the field at risk. Hybrid forages have proven to be a real alternative for enhancing both the food security and sustainability of the sector. They are the product of genetic improvements and combine the superior traits of different materials. In 1987, the International Center for Tropical Agriculture (CIAT) began this line of research and together with the private sector various materials have been released until today. Despite their beforementioned potential, forage hybrid adoption levels are still low in Africa, which is related to various factors among which the availability of seeds and planting material stands out. This document analyzes the potential markets for new forage hybrids adapted to the environmental conditions of eastern Africa and partially western Africa. Likewise, an estimation of the commercial value of these markets is provided. The results show a potential market of 414,388 ha for new interspecific hybrids of *Urochloa* and 528,409 ha for potential hybrids of *Megathyrsus maximus*, with approximate values of 73.5 and 101.1 million dollars, respectively. Ethiopia, Tanzania, and Kenya have a 70% market share for *Urochloa*, while South Sudan, Ethiopia, and Tanzania have a 67% share for *Megathyrsus maximus*. The results will help different actors in decision-making, i.e., regarding private sector investments in forage seed commercialization or public sector incentives supporting adoption processes, and thus contribute to increasing food security and sustainability in the region.

**Keywords:** potential markets; improved forages; food systems; food security; forage hybrids; nutrition

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## 1. Introduction

In East Africa, the cattle sector is strategic in the fight against hunger and poverty. It provides, at least partially, the livelihood for about 70% of the rural inhabitants in the dry areas of West and East Africa, i.e., for about 110 to 120 million people. Dryland cattle farmers only have 1-1.2 TLUs (Tropical Livestock Units) per capita which makes them vulnerable to deteriorations in their living conditions in the face of droughts, disease outbreaks, or any other type of unforeseen event [1]. As a livelihood, the sale of milk is the predominant way of obtaining benefits from cattle farming. It generates cash that covers the daily expenses of families such as food and medicine. Culling is less frequent, and cattle are savings, a store of value that generates income in the short term and that is saved for difficult periods or more important expenses in the future [2]. Regarding the production system, most of the farms in the region have a smaller area than necessary to maintain a cow and her calf, in such a way that the predominant practice is cut and carry of forages and cattle feeding in stables [3].

In the region there is scarcity and low quality of forage, which is accentuated in dry seasons [4]. The lack of quality, efficient, and sustainable production is manifested in poor supply levels. This is how food security in East Africa has worsened over time [5]. Between March and July 2022, in Kenya, Somalia, and Ethiopia, children suffering from acute hunger, malnutrition, and thirst grew from 7.25 million to nearly 10 million. Droughts and price increases over recent months exacerbate a problem that has historically characterized the region [5]. With this situation, a technological change in food systems is needed to overcome the problems of food security and malnutrition. The transition from traditional or low-productive pastures to sustainable forage-based cattle systems with high performance and nutritional quality should be a priority for decision makers. The adoption of improved forage materials by the producers will allow obtaining food of animal origin in greater quantity and quality. In an environment where poverty and famines are common, new forage technologies offer the opportunity to provide quality meat and milk to the most vulnerable population. In countries like Kenya, there have already been efforts to strengthen the commercialization of higher quality forage grass seeds and splits, such as *Urochloa* hybrids and varieties (syn. *Brachiaria*), such as Mulato II or Cayman, and *Megathyrsus maximus* (syn. *Panicum maximum*) varieties such as Mombasa and Siambaza [6]. Likewise, institutional, private, and research actors make efforts to promote the adoption of this type of materials [6].

The field of research that has led to these technological developments is plant breeding, which aims to genetically improve plants. The techniques used range from the selection of plants with desirable traits for their multiplication to highly complex molecular processes. In the last century, plant breeding has contributed significantly to raising crop yields [7]. The improved forages and forage hybrids developed e.g., by the International Center for Tropical Agriculture (CIAT) or the Brazilian Agricultural Research Corporation (EMBRAPA), can increase the productivity and quality of the dairy sector, thus improving food security, income, and living conditions of cattle producing families [4]. In addition to achieving this primary objective, the adoption of these technologies generates positive environmental externalities, such as a reduction in greenhouse gas emissions [8]. Plant breeding research for the future continues with the objectives of obtaining materials with higher nutritional quality, nitrogen-use-efficiency, and the ability to regenerate and avoid soil degradation [9]. Despite the advantages, the process faces challenges. It is affected by factors such as lack of knowledge, low state investment, and a poorly developed input and output market [8].

Under this scenario, an important potential market is observed. The superior characteristics in terms of productivity, adaptability to the environment, and nutritional quality of improved forage materials would allow a better awareness for producers to adopt them. With the purpose of contributing to the discussion about new forage hybrid technologies for cattle feeding, this article provides an analysis of potential market segments for East Africa and some West African countries. This study was conducted as part of the CGIAR Initiative on Market Intelligence, which seeks to expand the social impact of technologies in areas such as nutrition, gender equality, and climate change [10]. From a global perspective, this responds to various of the Sustainable Development Goals, such as no poverty (SDG-1), zero hunger (SDG-2), and climate action (SDG-13), among others. The forage hybrid market segments have been identified within the CGIAR EiB (Excellence in Breeding) and BPAT (Breeding Program Assessment Tool) programs. EiB aims to improve the modernization of crop improvement programs for farmers in low- and middle-income countries [11]. For its part, BPAT is a tool that allows a structured review of technical aspects, capacity, and components of existing breeding programs, with the purpose of increasing the rate of genetic gain [12].

The techniques used for the forage hybrid market segmentation and valuation were of quantitative nature. In the first instance, potential areas for new forage hybrids were estimated based on geographic information system (GIS) analysis and statistical techniques for multivariate cluster analysis. Second, the estimation of the commercial values of new forage hybrids were made using geometric averages for market prices. The analysis includes several countries in eastern and western Africa, namely Ethiopia, Kenya, South Sudan, Tanzania, Uganda Nigeria, and Mali, which were identified in 2020 as part of the EiB and BPAT analyses of CIAT's Tropical Forages Breeding Programs. The results indicate significant opportunities for the development of these markets, i.e., for private sector involvement in seed production and commercialization. The document is

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composed of this introduction, a section on materials and methods, the results, the discussion, and the conclusions.

## 2. Materials and Methods

### *2.1. Methodological Background and Brief Literature Review on Similar Studies*

This section provides a description of the main results of studies on market analysis and potential adoption of new technologies in agricultural systems. Research ranges from basic survey analysis, discrete choice models, impact evaluations to multivariate techniques and GIS such as the one used in this article.

In Indonesia, for example, through a sample of 182 farmers, the demand for clean potato seeds in formal and informal markets was analyzed, obtaining an estimate of the willingness to pay for a higher quality seed. This study found that potato growers understand the advantages of these seeds and that the main limitation is high prices. However, the study estimates that a high number of farmers would obtain benefits from these materials, since yield differences between 30% and 50% are estimated. In some markets this would increase the willingness to pay by up to 37%. The study concludes that information on the reputation of seed producers is a determining factor for adopting a technology [13]. In Kenya, the potential adoption of developing biotechnologies that protect maize from various types of fungi was analyzed. In a sample of 480 households, a potential adoption of 82% of these technologies was estimated with a logistic discrete choice model. The model allowed to infer that both formal education and knowledge of the new technology influence adoption. Likewise, high-income farmers are more willing to make changes to their production systems. The condition of poverty generates significant risk aversion and is a limitation for adoption. Given this, the study concludes that policy efforts should be focused on encouraging the adoption rate among this population [14].

There is another range of research that uses impact evaluation methodologies with the objective of estimating the potential adoption of improved crop technologies, in particular by estimating the average treatment effect (ATE). In this context, the treatment poses scenarios in which the population is exposed to the knowledge of the new technology and has the ability to access the product. In such a way that results of actual and potential adoptions are obtained. Following this approach, an evaluation in Nigeria estimated the potential adoption of new rice varieties using a probit model. Producers with a higher educational level, age, access to extension services, and knowledge of local varieties were more likely to know and acquire improved seeds. The actual adoption rate was 19%. The results indicate that having the knowledge places the adoption potential at 54% and if producers can obtain the new seed, the value increases to 62% [15]. In Benin, the adoption of improved corn varieties was evaluated in a sample of 490 farmers with a probit model approach. The results revealed that literacy, the relationship with institutions, the area planted with corn, and income from corn production are the main determinants of adoption. 84% of the producers knew the improved seed, with which the adoption was located at 78%. A global knowledge of the technology would imply a potential adoption of 93% [16]. A study in Uganda shows the potential adoption of drought-resistant maize in three scenarios, based on three probit models for the evaluation, referring to a) the producer's knowledge of the new technology, b) producer knowledge and availability of planting material, and c) producer knowledge, availability of planting material, and affordable market prices. Based on this, an actual adoption rate of 14% was estimated. The potential adoption rates for the three scenarios were 22%, 30%, and 47%, respectively. The study recommends strengthening credit lines to facilitate access to seeds as well as developing subsidy programs for these materials [17]. In Mali, potential adoption rates for eight climate-smart agriculture technologies were estimated with a logit model. Among these are varieties of crops resistant to droughts, organic fertilizer, and agroforestry. With a sample of 300 families, the observed adoption was between 39% and 77%, depending on the technology. In terms of access to knowledge, potential adoption fluctuated between 55% and 81%. Among the factors that influence adoption, the number of farm workers, access to subsidies, and capacity building/training were [18]. The reviewed studies provide consensus on that the adoption

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of new technologies depends on the dissemination of both the technology itself and knowledge about it.

Another method of evaluating the potential market for new improved seed technologies are GIS and multivariate statistical analyses. These techniques use environmental data from official statistics and meteorological sources. For example, using a basin-level hydrological model and simulation techniques, the areas with the best yield of total aerial biomass and cocoa beans in the humid tropics of southeastern Mexico were identified. The objective was to identify the areas with the greatest potential for productivity and economic benefit. The results show that cocoa is profitable when more than 770 kg of grain/ha is produced and that there are 223,000 ha with potential for this crop. The study uses information on climate, hydrology, soil, plant growth, other environmental variables, and management practices [19]. In Nuevo León, Mexico, the areas with the best productive possibilities for 16 crops were identified using thermal data, soil type data, and thematic maps. Results show that basic grains, vegetables, and fruit trees are suitable in more than 50% of the region's agricultural area. Another relevant result is the more precise identification of regions with frost phenomena. The study highlights the importance of this type of analysis to reduce the risk involved in any business activity in the agricultural sector [20]. Also in Mexico, a potential market index at the state level was developed for corn by building the indicator with variables such as the area planted with traditional and improved varieties. This information was combined with socioeconomic data to obtain the areas with the greatest potential for adoption of improved materials. The regions with the best prospects are the Lower Pacific Tropics with 1,485,272, Valles Altos with 954,197, and the Humid Tropics with 534,279 bags of seed [21].

In the case of forages, the experience in the region shows a series of difficulties related to this technological change. The final decision is in the hands of the producers and this in turn depends on various elements [22]. Institutional, logistical, infrastructural, and information factors are important constraints for adoption. In East Africa, these bottlenecks have been identified through qualitative, quantitative, and mixed methods. In Tanzania, the climate, insufficient availability of seeds, technical deficiencies, low productivity of local livestock, low milk prices, and few incentives for labor in dry seasons are the determinants of low adoption rates of improved forages [23,24]. In Ethiopia, forage adoption is affected by poor transport infrastructure, which increases production costs. Similarly, logistical difficulties affect the distribution of surplus milk. These elements end up offsetting the productivity and profitability gains obtained with the adoption of improved forages [25,26]. Also in Ethiopia, political factors, such as high staff turnover in public institutions, affect the dynamics of the forage sector and create scenarios of uncertainty [26]. In Kenya, households with no land ownership, low educational level of the head of household, large families, and far away from markets are less likely to adopt forage technologies [27]. In Malawi, dairy processing is operating at 20% capacity and consumption is below the African average. Improved forages would significantly contribute to the development of the sector. However, ignorance of forage technologies, market entry barriers, and inadequate approaches in extension programs slow down the adoption of these materials [28]. Several of the studies agree that extension services are one of the main bottlenecks for the adoption and sustainability of new technologies. Technical support does not usually accompany all production stages, which generates significant losses in the early stages of development [23,24,28,29]. As literature shows, in order to face these limitations, it is necessary to consolidate relations between governments, the private sector, and research actors to sensitize the rural population about the productivity, cost, and sustainability advantages of new forage technologies. The superior characteristics of these materials must be assertively transmitted to producers to obtain a higher adoption rate. Likewise, it is necessary to strengthen the accompaniment of the institutional and scientific sectors to the producers to guarantee access to technical, administrative, and commercial training, which allows for long-term sustainability of the new technologies.

### *2.2. Market Segments According to the Characteristics of Improved Forages*

Potential markets for new hybrid materials of *Urochloa* and *Megathyrsus maximus* species are analyzed in this study [30,31]. Hybrids are the product of genetic improvements and combine the superior traits of different materials. CIAT began this line of research in 1987 with an interspecific breeding program with *U. brizantha* (CIAT-6294 cv. Marandú), *U. decumbens* (CIAT-0606, cv. Basilisk), and *U. ruziziensis* (BR4X-44-2) [32,33]. This research, together with the efforts of the private forage seed sector, allowed the formal release of several forage hybrids: *U.* hybrid cv. Mulato I and cv. Mulato II, *U.* hybrid cv. Cayman, *U.* hybrid cv. Camello and *U.* hybrid cv. Cobra [34,35]. All these *Urochloa* hybrids are interspecific, which means that different species of the same genus were crossed to obtain improved crops [36]. In Africa, the commercialization began with Mulato I and Mulato II in 2005, Cayman and Cobra followed in 2019, and Camello in 2020 (Papalotla 2022, personal communication). There are no hybrids of *Megathyrsus maximus* on the market yet, but they are under development. Hybrids of *U. humidicola* are also being developed but are aimed at moist soils [37] and therefore, not adapted to the East African conditions.

The predominant characteristics of the soils, the climate, and the agricultural practices are the key elements for the identification of potential forage hybrid markets. The information on the materials comes from measurements in the field of pilot experiments carried out in Colombia. For this purpose, CIAT's breeding programs identified areas with similar geographic and environmental characteristics to those of East Africa and applied initial trials. The large number of trials required at the early breeding stages made it unfeasible to develop these processes in Africa directly [38]; (V. Castiblanco, personal communication, June 13, 2019). The methodology section delves into the technical details of this procedure, since it is also part of the technique used to estimate the size of the potential markets.

The market for *Urochloa* interspecific hybrids is oriented to sub-humid tropical savannahs with low fertility and acid soils in eastern and southern Africa. An important feature of African soils is desertification. Desertification leads to declining crop yields and undermines the resilience of agriculture and pastoralism, fundamental foundations of subsistence farming in Africa [39]. Forages are used for grazing, where the cattle roam freely, and for cut-and-carry, where the animals remain in stables. Forage characteristics have been grouped mainly into performance, agronomic factors, response to pests and diseases, production systems, and seed production/multiplication. The projected performance of new *Urochloa* interspecific hybrids, based on initial testing by CIAT's breeding program, is described below. In the seed yield, it is expected that in optimal conditions it will be at a production level equal to or above the existing commercial offer in the market (Table 1). This same result is expected under extreme conditions such as drought, acid soils, waterlogging, and heat. This is of vital importance because it means greater productivity and efficiency, which allows new products to be competitively priced in the market. Likewise, superior results are expected regarding NUE, since it is essential to optimize productivity levels and contributes to sustainable development by reducing the use of resources. This is a key element for areas with low availability of inputs such as Africa [40].

Regarding forage quality, the pilot tests showed a crude protein (CP) content higher than or equal to 10.5% and an in vitro digestibility of dry matter (IVDMD) higher than or equal to 62%, on average. The CP reflects the protein percentage of a feed and its presence in forages is essential for animals that are in the growth and production stage [41]. The IVDMD is also a measure of food quality [42]. Regarding shade tolerance and palatability, measured on a scale of 1 to 9, they are expected to be between an intermediate to high level. Shade tolerance is important in silvo-pastoral systems [43], which are, however, still scarce in the region of interest. On the other hand, palatability is defined as the particularities of a plant that encourage its selection by animals [44].

Disease risk, measured on a scale of 1 to 5, is ranked equal to or less than two for *Rhizoctonia* leaf blight. Some studies indicate that up to 50% of *Urochloa* production in tropical areas is affected by this disease [45]. The analysis of resistance to insects is in the development stage of the phenotyping methodology. Existing hybrids show a good response to the spittlebug complex (Hemiptera: Cercopidae), but not so much to the *Tetranychus urticae* mite, known as red spider mite. This plague has occurred in some areas of Kenya, such as Busia and Bungoma, affecting mainly Mulato II and Basilisk [46].

The production system for which the technologies are aimed at is dryland cattle production. In rainfed agriculture, only rainwater stored in the soil profile is used, artificial irrigation techniques are not implemented [47], for which it adapts well to the characteristics of a good part of the soils in Africa. Of the set of elements mentioned, the characteristics considered essential are seed yields, forage quality (CP and IVDMD), and insect resistance.

The potential competitors for new interspecific hybrids of *Urochloa* currently available on the market are a) Mulato II, which brings together the best traits of other hybrids and is suitable for medium and low fertility soils, b) Cayman, for areas with flooding, c) Camello, for areas with long-lasting droughts, and d) Cobra, for cut-and-carry systems [35]. Table 1 lists the main characteristics of these forages.

**Table 1.** Potential competitors for new interspecific hybrids of *Urochloa.*

| Characteristics | Mulato II | Cayman | Camello | Cobra |
|---|---|---|---|---|
| Main features | Good response to drought, acid soils, and high temperatures Combines the best features of other hybrids | Tolerant to humidity and waterlogging | Drought tolerance, quick establishment, good for acid soils | High yield, vertical growth that facilitates cutting |
| Resistance to pests and diseases | spittlebug | spittlebug | spittlebug | spittlebug |
| Required soil fertility level | medium, high | humidity | medium | high (for higher yields) |
| Palatability | very good | very good | very good | very good |
| CP (%) | 14-22 | 10-17 | 14-16 | 14-16 |
| IVDMD (%) | 55-66 | 58-70 | 62 | 69 |
| Yield (t/ha/cut) | 25 | <24 | 27-30 | 35-40 |
| Main use | grazing | grazing | grazing | cut-and-carry |

Source: own elaboration based on [35,37,48–50].

On the other hand, the potential market for hybrids of *Megathyrsus maximus* is oriented to the sub-humid tropical savannah of eastern and southern Africa, with fertile soils, of high productivity, and intended particularly for cut-and-carry systems. According to the measurements of the pilot tests carried out in Colombia, the seed yield in optimal conditions is expected to be higher than the commercial offer on the market (Table 2), even in extreme conditions such as drought, acid soils, waterlogging, heat, and considering NUE. Regarding forage quality, CP and IVDMD levels are estimated to be greater than or equal to 10.5% and 62%, respectively. Biological Nitrification Inhibition (BNI) is estimated to be moderate to high. BNI refers to the compounds that forages generate and that inhibit nitrification in the soil, which reduces or eliminates the use of fertilizers and thus generates savings in production costs as well as mitigates greenhouse gas emissions [51]. The production system is rainfed. On the market, the competing products for this new material are a) *Megathyrsus maximus* cv. Mombasa, which has a great overall performance, b) *Megathyrsus maximus* cv. Tanzania, for soils with medium and high fertility, c) *Megathyrsus maximus* cv. Massai, with high biomass production but drought sensitivity, and d) *Urochloa* hybrid cv. Mavuno, which has good drought tolerance and yields [37,49,52–54]. Table 2 summarizes the main characteristics of these forages.

**Table 2.** Potential competitors for new *Megathyrsus maximus* hybrids.

| Characteristics | Mombasa | Tanzania | Massai | Mavuno* |
|---|---|---|---|---|
| Main features | High regrowth rate and good stem-leaf-ratio<br>Medium tolerance to cold and burning<br>Good drought tolerance | Medium drought tolerance | Burn and shade tolerance<br>Reduced yield by 50% in dry season | Good tolerance to drought, burning, and shade<br>Medium tolerance to humidity |
| Resistance to pests and diseases | spittlebug | spittlebug<br>medium tolerance to coal in the inflorescences | spittlebug<br>sensitive to panicle rot caused by T. ayresii (<80% of inflorescences) | spittlebug |
| Required soil fertility level | medium to high acid soils | medium to high acid soils | low to medium acid soils | medium acid soils |
| Palatability | very good | good | good | very good |
| CP (%) | 10-14 | 10-12 | 7-11 | 18-21 |
| IVDMD (%) | 60-65 | 62 | 55-60 | 60 |
| Yield (t/ha/cut) | 25 | 18-20 | 21 | 17-20 |
| Main use | grazing<br>cut-and-carry | grazing<br>cut-and-carry | grazing<br>cut-and-carry | grazing<br>cut-and-carry |

Source: own elaboration based on [37,49,52–54]. *Mavuno was released by Wolf Sementes from Brazil in 2013 [37]. Despite being an *Urochloa* hybrid, due to its high performance it is considered a potential competitor in the *Megathyrsus maximus* market.

### 2.3. Information Sources

Given that dairy production is the most relevant cattle activity in the region, the quantitative approximation of the potential hectares of new hybrid forages is based on the information on cattle heads destined for dairy production. In the FAOSTAT data platform of the Food and Agriculture Organization of the United Nations (FAO), production, crops, and livestock products were entered, and the information was filtered according to the required criteria [55]. In "element", animals in production were chosen. In "product", primary livestock (list) was displayed by choosing the option "raw milk from bovine cattle". Finally, the year 2020 and the countries of interest were selected. The process produced a data table with the information on the heads of dairy cattle per country. In the calculation this information will be converted into hectares of forages required to feed these animals.

To define the percentage of adoption of each material, the Target Population of Environments (TPE) study of CIAT's forage breeding programs was used (V. Castiblanco; A. Notenbaert, personal communication, June 13, 2019), by which the areas that are most suitable for the evaluated forage materials were identified [38]. Information on the market prices of different forage seeds was obtained from the prices published by different seed distributors on electronic commerce platforms for the second half of 2022.

### 2.4. Method for the Estimation of Potential Markets and Market Values

This section describes the method used by CIAT's breeding program to estimate potential markets for new interspecific *Urochloa* Megathyrsus maximus hybrids in East Africa, particularly in Ethiopia, Kenya, Tanzania, Uganda, and South Sudan. Results are also presented for two West African countries, namely Mali and Nigeria. The first step was the identification of the potential hectares for these hybrids. With data from the FAO on cattle heads for dairy production for the year 2020, the number of hectares required for forage cultivation was calculated. The estimated area is a conservative assumption since improved forages have superior performance and require fewer hectares for the same level of production than other materials. The estimation considered the following assumptions: A daily green matter requirement of 60 kg per animal, a forage adoption rate of 15% per year, and a green matter yield of 60 tons per hectare and year.

By means of Equations (1) and (2) the calculation of the potential hectares was carried out. Equation (1) gives the annual forage requirement in tons. With Equation (2), the hectares of forages required to feed the animals were obtained. The measurement is in green matter.

$$\mathrm{RAFT} = \frac{\mathrm{RDFK} * 365\ \text{días} * \mathrm{CRL}}{1.000}, \quad (1)$$

where RAFT is the annual forage requirement in tons, RDFK is the daily forage requirement in kg, and CRL is the number of dairy cattle heads. Substituting this result in Equation (2), the potential hectares are obtained,

$$\mathrm{HaP} = \frac{\mathrm{RAFT} * \mathrm{AR}}{\mathrm{Ytha}}, \quad (2)$$

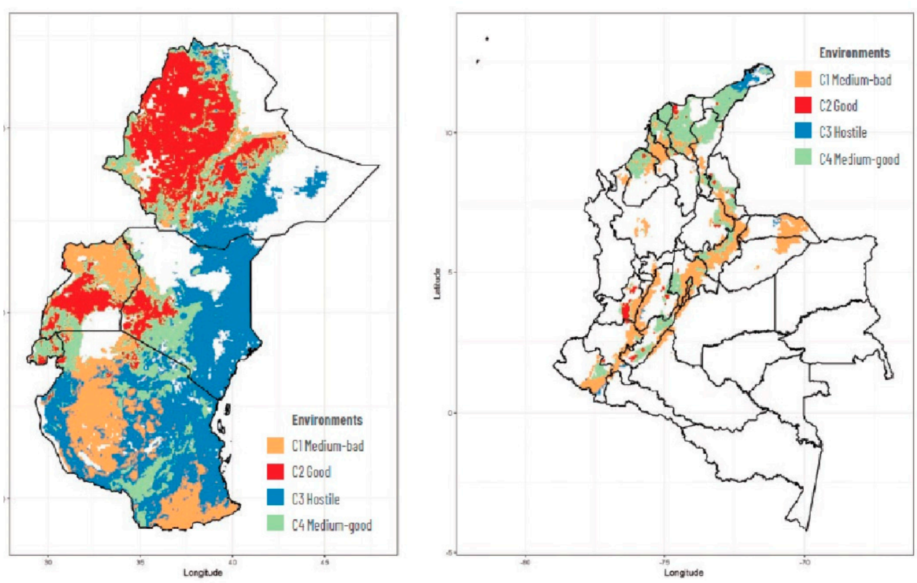
HaP are the potential forage hectares required for forage cultivation, AR is the adoption rate, and Ytha is the average forage yield per hectare in tons. For example, in 2020, Kenya had 5,112,340 dairy cattle. According to this and the established assumptions, this leads to the following estimation for the annual forage requirement:

$$\mathrm{RAFT} = \frac{60\ \mathrm{kg} * 365\ \mathrm{d} * 5.112.340}{1.000} = 111.960.246\ \text{tons}, \quad (3)$$

and for the potential hectares required for forage cultivation:

$$\mathrm{HaP} = \frac{111.960.246\ \mathrm{t} * 15\%}{60} = 279.901\ \mathrm{ha}, \quad (4)$$

The second step was to assign a proportion of these hectares to each of the two materials of interest (interspecific *Urochloa* and *Megathyrsus maximus* hybrids). This proportion was obtained from the TPE study (V. Castiblanco; A. Notenbaert, personal communication, June 13, 2019) [38]. CIAT's forage breeding program developed this technique using GIS and multivariate cluster analysis, and in this way, areas with similar environmental traits in Africa and Colombia were identified [38], as shown in Figure 1. This allowed the pilot experiment referenced in the market segments section to be carried out in Colombia. Likewise, the profiling formed four geographic groups with similar environmental characteristics, considering areas of high cattle density [56], soil quality data [57], and different precipitation levels [58,59].




(a) (b)

**Figure 1.** (**a**) Identified clusters for East Africa and (**b**) Colombia [38].

For this analysis, two groups are relevant, namely a) Cluster 2 (good), colored red on the maps, and characterized by higher precipitation levels and better rainfall distribution throughout the year. It provides the conditions for the adoption of potential *Megathyrsus maximus* hybrids, which have high quality and productivity levels, but require good environmental conditions. Cluster 2 represents 28% of the potential area. And b) Cluster 3 (hostile), colored blue on the maps, and characterized by low precipitation levels and poor rainfall distribution throughout the year. It provides the conditions for new interspecific *Urochloa* hybrids, which have a medium to high productivity and are very adaptable to difficult environments. Cluster 3 represents 27% of the potential area [38]. By applying these percentages to the hectares calculated in the first step, the potential markets for the new interspecific *Urochloa* and *Megathyrsus maximus* hybrids were obtained. This was done for each of the countries of interest. It is important to emphasize that, although some data sources were not so recent, GIS analysis provides valuable geospatial information by incorporating a large number of variables, which allow for segmentation with a good level of certainty.

Finally, the commercial value of the identified market segments was estimated, consulting average market prices for the materials considered as competitors for new interspecific *Urochloa* and *Megathyrsus maximus* hybrids (see Tables 1 and 2). Due to the high research and development costs, among others, forage hybrid seeds have a higher market price than other forage varieties. Regarding *Megathyrsus maximus*, there are no hybrid materials available on the market yet, for which direct price references are missing. To obtain market price estimations for these hybrids, the price difference between interspecific *Urochloa* hybrids and other commercial *Urochloa* varieties was applied to the case of *Megathyrsus maximus*, too. For this, geometric averages were used, as they better capture price dynamics [60]. Equations (5) and (6) allow obtaining the respective values:

$$\mathrm{PMU} = \sqrt[n]{P_1 * P_2 * \quad * P_n}, \tag{5}$$

$$\mathrm{PMM} = \mathrm{h} * \sqrt[n]{P_1 * P_2 * \quad * P_n}, \quad con\ \ h > 0 \tag{6}$$

Where PMU and PMM are the averages market prices of *Urochloa* and *Megathyrsus maximus*, respectively. The term h represents the margin that increases the price to level it to the hybrids and n corresponds to the number of data used for the calculation.

Finally, the value of each market was expressed according to Equation (7):

$$\mathrm{Vm} = \mathrm{A} * \mathrm{S} * \mathrm{P}, \tag{7}$$

The market value (Vm) was calculated for each hybrid, considering the potential area in hectares (A), the seed needed per ha (S) and the market price (P) of one kg of seed. Following the literature on the subject, 7 kg of forage hybrid seed are required for each ha [61]. The average market prices for *Urochloa* and *Megathyrsus maximus* varieties were US$ 18.42 and US$ 19.87, per kg of seed respectively, and for the existing interspecific *Urochloa* hybrids US$ 25.35. The price premium for *Urochloa* hybrids can thus be estimated with 37.63%. Applying this price premium to the case of *Megathyrsus maximus* results in a potential market price of US$ 27.34 for a kg of hybrid seed.

## 3. Results

Dairy production is the most representative cattle activity in the region of analysis. According to the FAO, the dairy cattle herd in Africa for 2020 reached 66,330,001 heads. The largest inventory is concentrated in East Africa, which holds 34,723,481 dairy cattle. Within this region, the largest volumes are found in South Sudan (8,432,559 dairy cattle), followed by Ethiopia (7,556,402), Tanzania (7,116,771), Kenya (5,112,340), and Uganda (4,037,038). Of less importance are Somalia (1,186,851), Rwanda (335,087), Zambia (279,630), Burundi (279,630), and Malawi (110,394) [55]. To understand the relative importance of the dairy sector, some figures regarding beef cattle are important to consider, since its participation in the region is lower. Africa counts with a total beef cattle herd of 41,720,252 heads, and in East Africa there are about 14,527,659 beef cattle. The countries with the highest inventory of beef cattle in the region are Ethiopia (4,086,481 beef cattle), Tanzania (3,554,364), Kenya (1,953,734), Uganda (1,217,247), and Zambia (1,065,054). The lowest inventories are found in

South Sudan (964,884), Malawi (529,461), Somalia (510,000), Rwanda (476,119), and Burundi (63,287) [55]. Given the importance of the dairy sector, the information on dairy cattle was taken to estimate potential hectares of improved forages needed to feed the animals according to the methodology exposed in the previous section.

The results of the estimation for the potential market of new interspecific hybrids of *Urochloa* can be observed in Figure 2a. The biggest prospects for this market in East Africa are found in Ethiopia, Tanzania, Kenya, and Uganda. Other representative countries outside the region are Nigeria and Mali from West Africa. The main opportunity is observed in Ethiopia with a potential of 111,703 ha for interspecific *Urochloa* hybrids, followed by Tanzania and Kenya with 105,204 and 75,573 ha, respectively. Uganda and Nigeria are in the middle range with 59,678 and 32,726 ha, respectively, and Mali, another country from West Africa holds the smallest market potential (29,505 ha). These figures imply that the mere participation of Ethiopia, Tanzania, and Kenya represents about 70% of the potential area of adoption of new interspecific *Urochloa* hybrids in the analyzed countries, and 83% when only the East African countries are considered.

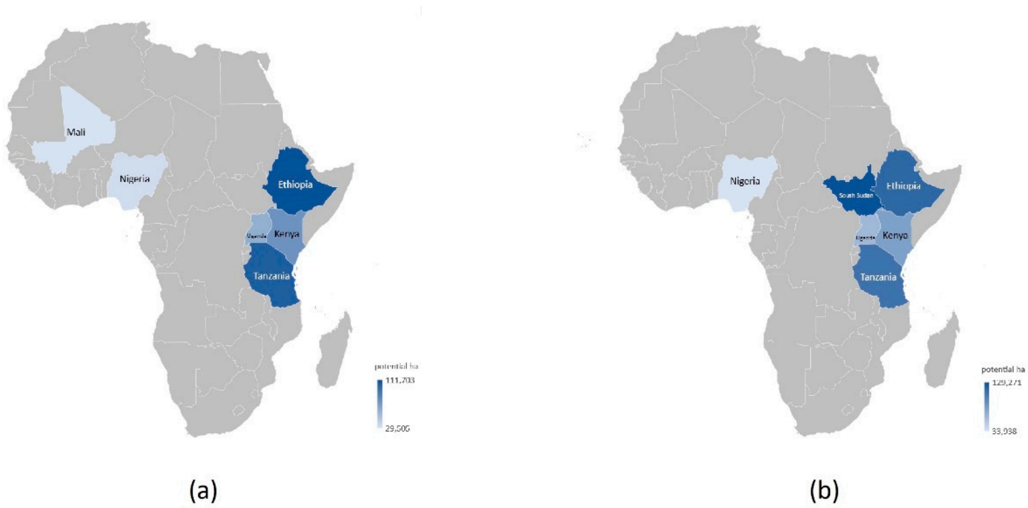



**Figure 2.** Potential markets for new interspecific *Urochloa* (**a**) and *Megathyrsus maximus* (**b**) hybrids. Source: own elaboration based on [38] and (V. Castiblanco and A. Notenbaert personal communication, June 13, 2019).

Figure 2b shows the results for the potential market of *Megathyrsus maximus* hybrids. South Sudan holds the biggest market potential with 129,271 ha. It is followed by Ethiopia (115,840 ha), Tanzania (109,100 ha), Kenya (78,372 ha), and Uganda (61,888 ha). In West Africa, Nigeria offers a potential market for *Megathyrsus maximus* hybrids of 33,938 ha. These figures imply that the mere participation of South Sudan, Ethiopia, and Tanzania represents about 67% of the potential area of adoption of *Megathyrsus maximus* hybrids in the analyzed countries, and 72% when only the East African countries are considered.

These results show which are the most representative markets in the analyzed countries, according to areas best suited to adopt one of the two technologies of analysis. The estimation of the commercial value complements this analysis and is an essential element for decision-making by dairy producers, the private forage seed sector, and the public sector. The estimated annual market values in millions of US$ are presented in Figure 3. The total annual market value for both technologies is estimated at US$ 174,665,945, out of which *Megathrysus maximus* hybrids make up 58% and new interspecific *Urochloa* hybrids 42%. Regarding new interspecific *Urochloa* hybrids, the annual market value is US$ 73,521,066, and the largest market shares are held by Ethiopia, Tanzania, and Kenya with values close to 19.8, 18.6, and 13.4 million US$, respectively. Regarding *Megathyrsus maximus* hybrids, the annual market value is US$ 101,144,879, and the largest market shares are held by South Sudan, Ethiopia, and Tanzania with values close to 24.7, 22.1 and 20.8 million US$, respectively.

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**Figure 3.** Estimated annual market values in millions of dollars for new interspecific *Urochloa* (**a**) and *Megathyrsus maximus* (**b**) hybrids. Source: own elaboration.

On the other hand, it should be noted that the assumption of an adoption rate of 15% implies, at least theoretically, that the adoption of the new materials can occur in less than seven years, which means that the total market values for new interspecific *Urochloa* and *Megathyrsus maximus* hybrids would be US$ 490,140,439 and USD 674,299,195, respectively.

## 4. Discussion

This study estimated the potential markets for new forage hybrids in East Africa and some West African countries. The results show significant possibilities for both the commercialization of the hybrid seeds and their adoption by dairy farmers. Growing improved forages as feed for dairy cattle is a valuable alternative to address the problems of food security and malnutrition in the region, since they increase both animal productivity and meat and milk quality. In this way, the change from production systems based on traditional pastures to systems that involve highly productive and more sustainable technologies would have positive effects on the poorest and most vulnerable population.

Most market research on improved crops focuses on identifying and delimiting the geographical areas with the greatest possibilities for adoption. However, studies that estimate commercial values of improved forages are scarce. Private research companies such as Morder Intelligence value the global forage market for 2020 at ~20,33 billion US$ and project that by 2026 it will reach ~30,91 billion US$ [62]. Calculations for Brazil indicate that in 2019, the seed trade for tropical grasses exceeded 1.4 billion Reais, which is equivalent to almost 269 million US$, noting that low-quality seeds participate with 30% of the total market [63]. The proposal presented in this article combined two methodological approaches, namely (i) the estimation of potential areas where two hybrid forages (new interspecific *Urochloa* hybrids, *Megathyrsus maximus* hybrids) can be planted and the amount that is needed by the dairy cattle herd present in the countries of analysis, considering specific environmental and productive conditions present in the region of analysis, and (ii) the estimation of the commercial value for each of the two technologies in each of the analyzed countries. For the analyzed countries, a potential market of 414,388 ha and 528,409 ha was found with approximate annual monetary values of 73.5 and 101.1 million US$, respectively. This fits into the context provided by a study on the extent and economic significance of cultivated forages in developing countries, where the current total value of planted forages in developing countries was estimated at 63 billion US$ corresponding to a coverage of 159 million hectares [64].

Although there are no studies that delve into this type of analysis for tropical forages, geographic profiling techniques through environmental, climatic, and edaphic conditions have been implemented to evaluate a set of different other crops. In Mexico, for example, in a study on potential areas for cocoa production in the humid tropics, 223,000 ha were estimated as suitable [19]. Also in Mexico, in Nuevo León, an environmental profiling study identified that there is a great capacity to produce basic grains, vegetables, and fruit trees in more than 50% of the surface devoted to agriculture [20]. Another study in Mexico estimated the potential for improved maize seeds in 2012 and identified that in the Lower Pacific Tropic region the actual production is 750,000 seed bags while the potential production could be 1,485,272 seed bags, and in the Humid Tropics it could even go from 80,000 to 534,279 seed bags. Likewise, areas where there is no improved seed production yet, a potential for its establishment was identified. For example, in Valles Centrales and Trópico Bajo Atlántico where the potential was estimated to be of 122,712 and 518,473 seed bags, respectively. In the national aggregate, the calculated real production was 2,660,000 seed bags and the market potential was estimated at 4,988,034 seed bags [21]. In this sense, these studies are in line with the methodological approach used in this article regarding two aspects, namely: a) the identification of potential areas to successfully implement a specific crop, and b) the identification of the production potential to be significantly higher than the current one, given the expected yields of the new technologies with superior characteristics.

There also exist market studies for improved crops that follow a willingness to pay perspective. They consist of answering the question of how much a producer is willing to pay for a higher quality seed without affecting its economic benefit. In a context where buyers are aware of the improved characteristics of new materials, willingness to pay is expected to be higher, since a greater investment will be compensated by efficiency gains, as well as higher productivity and income. Research in Indonesia identified that the willingness to pay for improved potato seed, for some farmers, could absorb price increases in private sector markets of between 6% and 37% [13]. In this article, a similar analysis was carried out, but from a point of view of hybrid seed suppliers and for the case of *Megathyrsus maximus*, which does not have hybrids on the market yet that would serve for price comparison and guidance. To get an idea of the price of a higher quality material of *Megathyrsus maximus*, the *Urochloa* market was considered where both traditional and hybrid lines are already available. Based on this differential, the potential price premium for hybrid seeds of *Megathyrsus maximus* was estimated at 37%.

Another set of studies aims at estimating actual and potential adoption rates through impact evaluation techniques [15–18]. Although they are not focused on market segmentation by product, as is the objective of this research, they do contribute to the discussion by providing empirical evidence on the importance of adoption factors, such as the dissemination of knowledge and provision technical assistance to the potential users of the new technologies. The present study did not focus on the analysis of adoption factors but instead on providing decision-making support for the forages seed sector on potential opportunities for investment. However, investments in forage hybrid seed production and dissemination alone will not suffice to increase adoption rates of new technologies among dairy producers in East Africa despite tackling the lack of basic seed [65]. Literature, mostly on the Latin American context where the adoption of cultivated forages is more advanced compared to East Africa, shows that it depends on numerous additional factors. These include e.g., risk factors (risk aversion, perception of risks regarding future returns) [66–68], knowledge and information about the technology itself (establishment and management processes and costs, benefits and risks associated with the technology) [69–71], labor requirements [72], access to productive inputs and capital (credit) [73–75], product differentiation strategies [76], extension and technical assistance [70,77–81], the knowledge and innovation system [80,82,83], social capital and social networks (e.g., through farmer groups) [84–89], land prices, land tenure, land speculation [72,90,91], existing and evolving regulatory frameworks and political/institutional factors [92–94], and conflict [95].

## 5. Conclusions

The estimations of potential markets for new *Urochloa* and *Megathyrsus maximus* hybrid forages for the dairy sector in East Africa provided in this article show an opportunity for making an important change in the local food systems. Moving from dairy systems based on traditional or low-quality pastures towards systems that integrate improved forage materials provides opportunities for improving both the availability and nutritional quality of animal source food, i.e., milk, and thus contributes to achieving food security and combating hunger in the region. Likewise, taking advantage of and developing these markets implies an opportunity to promote a sector that has the capacity to generate income and livelihoods for the most vulnerable part of the population. From a point of view of economic development, the promotion and consolidation of these markets is an effective economic policy to improve indicators of poverty, unemployment, growth, and price stability. Dairy is a fundamental activity for the economic structure in the region and its development has a positive impact on the entire macroeconomic environment.

The technological change required for the development of potential markets requires that adequate market conditions exist. In this sense, it is important to generate a favorable commercial and institutional environment for the adoption of improved forages. This is a determining element since it will provide the necessary incentives for producers to make adoption decisions in their production system. Alongside, communication between the various actors must be promoted to identify the advances and difficulties that arise with the adoption of new forage technologies. An adequate information system is essential for decision makers to establish policies and implement timely actions according to the local contexts. Considering these aspects is essential for the development of a competitive forage seed market so that promising materials can be properly registered and made available to farmers.

Literature reviewed in this article reveals that providing improved forage seeds alone is not guaranteeing widespread adoption among farmers and that adoption ultimately depends on a broad set of factors that must be considered in technology development, promotion, and dissemination strategies. For example, forage hybrids tend to be more expensive than other commercial varieties putting access to credit at the center of discussion. Likewise, forage hybrids have different requirements in terms of establishment and management and generate different costs and benefits, requiring the development of new sets of knowledge and accessible extension and technical assistance programs.

This study also shows that market studies on improved forages are scarce. The results provide relevant information to better understand the possibilities and economic opportunities that a massification of new forage hybrids could have. Similarly, market segmentation allows reducing the levels of uncertainty in terms of where to promote different types of new technologies and thus reduces the risks associated with adoption. This is key since the ultimate objective of plant breeding is to develop new and superior technologies that are adopted by farmers and contribute to changing their livelihoods.

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