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Forage crops status, determinants and constraints: Current status of improved forage crops, determinants and constraints on smallholders mixed crop-livestock farms in the semi-arid region of Algeria

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Abstract: In Algeria, forage crops face significant limitations, posing a challenge to the development of intensive livestock production. This study aims to understand the status, determinants, and constraints to the adoption of improved forage crops in mixed crop-livestock family farms in the province of Bordj Bou Arreridj, located in the semi-arid zone of eastern Algeria. We conducted a survey on 98 farms using a semi-structured questionnaire in two different ago-pedoclimatic zones, and our analysis included the description of forage cropping modalities and the empirical modelling of the factors influencing the adopted patterns of forage crops. Our results showed that fodder crops cover almost 20% of the total arable land. However, the allocation of land to forage crops varied considerably between farms and zones. Cultivated forage crops included barley, oats, corn, sorghum, and alfalfa. The adoption of improved fodder crops was influenced by several structural and socio-economic factors, such as exploited farmland size, size of sheep livestock, family labor size, access and permanent availability of irrigation water, farming equipment, social network involvement, and agricultural training. The development of forage crops encountered various constraints, including issues of seed availability and cost, limited farmland, and insufficient irrigation water. To boost forage incorporation in local farming systems, it is imperative to raise farmers' awareness of the agronomic benefits of cultivating fodder crops. In addition, supporting farmers to improve their knowledge, farm structures, and equipment and providing seeds and fertilizers are crucial for the successful promotion of fodder crops.

Keywords: Improved forage, Cropping system, Livestock system, Feed autonomy, Semi-arid

Introduction

In underdeveloped regions, forage is the principal source of nutrition for most ruminant livestock (Capstaff & Miller, 2018; Fuglie et al., 2021) and forage availability plays an important role in livestock development and sustainable livestock farming (Guyader et al., 2016; Ramesh et al., 2021; Tulu et al., 2023). Adequate quantities of high-quality forage are necessary for profitable livestock production (Turinawe et al., 2012; Makkar, 2016), and low incorporation of forage into livestock feed leads to low productivity, low product quality, and poor health (Devendra & Leng, 2011; Davis et al., 2020; Harris-Coble et al., 2022).

Forage generally has two main sources: natural forage and cultivated forage. These forages can be utilized directly through grazing or conserved as hay or silage (Finch et al. 2014, Collins et al., 2017; Bybee-Finley et al., 2018). However, across arid, semi-arid, and Mediterranean regions, natural forage is subject to seasonal variability. Its availability is increasingly affected by climate change and land degradation (Abusuwar & Ahmed, 2010; Gilhaus et al., 2016; Ergon et al., 2018; Mutimura et al., 2019; Giridhar & Samireddypalle, 2015; Dagar et al., 2017; Cheng et al., 2022).Which become a significant challenge for livestock development in these regions (Makkar, 2012; Mengistu et al., 2017; Amad & Zentek, 2023). Therefore, Forage production is one of the greatest challenges faced by livestock farmers (Gunasekaran et al., 2019; Shit, 2019) based on the role that can play in supporting livestock farms during periods of feed scarcity (Paul et al., 2020; Junca Paredes et al., 2023). Cultivated forage reduces livestock production costs, enhances profitability, and supports the production of high-quality, affordable animal-derived food (Grover & Kumar, 2012; Makkar, 2016; Vinita et al., 2023; Henzell, 2019; Junca Paredes et al., 2023). Improved forage cropping is vital for enhancing livestock productivity and resilience. Achieving sustainable livestock production requires overcoming key challenges in forage crop development (Birhanu et al., 2017; Fenetahun et al., 2019; Tlahig et al., 2024; Singh et al., 2022).

In mixed crop-livestock farming systems, forage crops plays a central role in agronomic sustainability (Ates et al., 2018). Diversifying forage crop rotations with annual crops provides many benefits and ecosystem services (Rao et al., 2015; Annicchiarico et al., 2017; Franzluebbers & Martin, 2022; Picasso et al., 2022). Forage crops can reduce pressure on degraded pastureland (Mengistu et al., 2016; Fuglie et al., 2021) and are considered a low-cost method for soil conservation and improvement of soil properties (Koudahe et al., 2022; Pushpanjali et al., 2022). It help to increase carbon sequestration, managing root diseases and increasing biodiversity, (Entz et al., 2002; dos Santos et al., 2011; Martens et al., 2015; Notenbaert et al., 2021). It can further contribute into reducing nitrogen fertilizer and energy costs associated with applying nutrients (Singh et al., 2012). Moreover, improved forage legumes have been identified as particularly valuable for reducing environmental trade-offs, such as greenhouse gas emissions from livestock systems (Peters et al., 2013; Boddey et al., 2020).

Forage production varies significantly across regions, influenced by factors such as cropping patterns, climate, socioeconomic conditions, and livestock types (Dagar, 2017). Understanding the status of forage production within farming systems is essential to identify regional needs and implement tailored policies (Díaz de Otálora et al., 2022). On crop-livestock farms, forage production reflects complex interactions between agriculture and livestock, necessitating a whole-farm approach to study these dynamics. Therefore, farming systems approaches play an important role in exploring the integration of forage crops and their interactions with various farm components (Paul, 2019) and systemic thinking is crucial for understanding farms' adaptation to forage technologies (Paul et al., 2020; Morrison et al., 2023). Understanding farm structures and socioeconomic characteristics is equally important, as it helps identify effective strategies to enhance forage production (Cevher & Altunkaynak, 2020). Furthermore, analysing the factors influencing the form of adoption reveals their dual benefits: providing livestock feed while promoting soil conservation (Lapar & Ehui, 2004).

Livestock production is an important component of farming systems in Algeria as many developing countries. However, livestock feed production remains limited. Livestock feeding relies mostly on grazing natural forage resources and crop residue after harvest (Abbas & Abdelguerfi, 2005; Mebarkia et al., 2020; Mahmah et al., 2023). Land involved in forage production accounts for 40 million hectares, and Algeria's forage area represents 2.6% of the area used for agriculture, but cultivated forage represents less than 2 % of the country's total forage area (Senoussi & Behir, 2010; Zirmi-Zembri & Kadi, 2016). Livestock needs cannot be met by the current forage supply, and forage availability is considered by many researchers and agro-economists as an obstacle to the development of intensive livestock farming (Bir, 2019; Sofia et al., 2023). Despite the efforts of several researchers in forage breeding (Abbas et al., 2014; Mefti et al., 2016; Achir et al., 2020; Mebarkia et al., 2020; Mahmah et al., 2023), limited attention has been given to the actual status of cultivated forage at the farm level. Only a few studies have specifically addressed this issue on dairy cattle farms (Kadi & Djellal, 2009; Ghozlane et al., 2021; Sofia et al., 2023). Moreover, in Algeria, no research has yet explored the status of forage production within smallholder mixed farming systems, nor its systemic drivers and barriers to adoption.

This study aims to explore forage cops production status and highlight the socio-economic and structural factors that affect improved forage adoption in family farms in the semi-arid region of eastern Algeria. This also includes constraints encountered in developing an intensive forage production activity. This serves as a means of understanding the elements that influence farmers' choices and the obstacles that hinder the expansion of cultivated forage in order to develop efficient strategies for intervention, technology transfer, and support. In addition, this can be a means of identifying the levers of livestock farm feed autonomy, and one of the most important factors that control the resilience of local farming systems, especially under the increasingly observed impacts of climate change in this region.

Materiel and methods

Study area

The present study was carried out in the province of Bodj Bou Arreridj in northeast Algeria. Its geographical coordinates were 36°04'23″ N and 4°45'39″ E with a total area of 81.10 km². This region is characterized by hilly and rugged terrain, with elevations ranging from 600 to 1,500 m above sea level, and an average elevation of 928 m. The area is characterized by a variety of agro-pedo-climatic zones. The northern zone is formed by a mountain range, while the southern part of the area is a sub-steppe and is mainly used for agro-pastoral purposes. In the center, the land consists of high plains, making the region excellent for agriculture. The climate is semi-arid continental, with harsh, very cold winters, and hot, dry summers. Rainfall ranges between 300 and 600 mm, and there are differences in rainfall with altitude between different areas of the province (Figure 1).

Data collection

A cross-sectional survey was conducted on 98 randomly selected family farms in the Bordj Bou Arreridj Province, which incorporated forage crops into their crop systems. Surveys were conducted between February 15 and March 20, 2023. Farm selection was based on the guidance provided by the managers of agricultural services. The surveyed farms were located within two distinct agro-pedo-climatic zones defined by their pedoclimatic characteristics (Figure 01). The high agronomic potential (HAP) zone is characterized by relatively high rainfall (>500 mm/year) and fertile clay loam soils, making it highly suitable for agricultural activities. In contrast, the low agronomic potential (LAP) zone receives less rainfall (<500 mm/year) and features less fertile silty-sandy calcareous soils. Face-to-face interviews were conducted with the head of the household or farm manager using a semi-structured questionnaire. The questionnaire, developed in collaboration with experts in livestock and farming systems, included sections covering household characteristics, farm structure and equipment, land use and cropping patterns, cultivated forage species, herd composition and size, and overall farming practices.

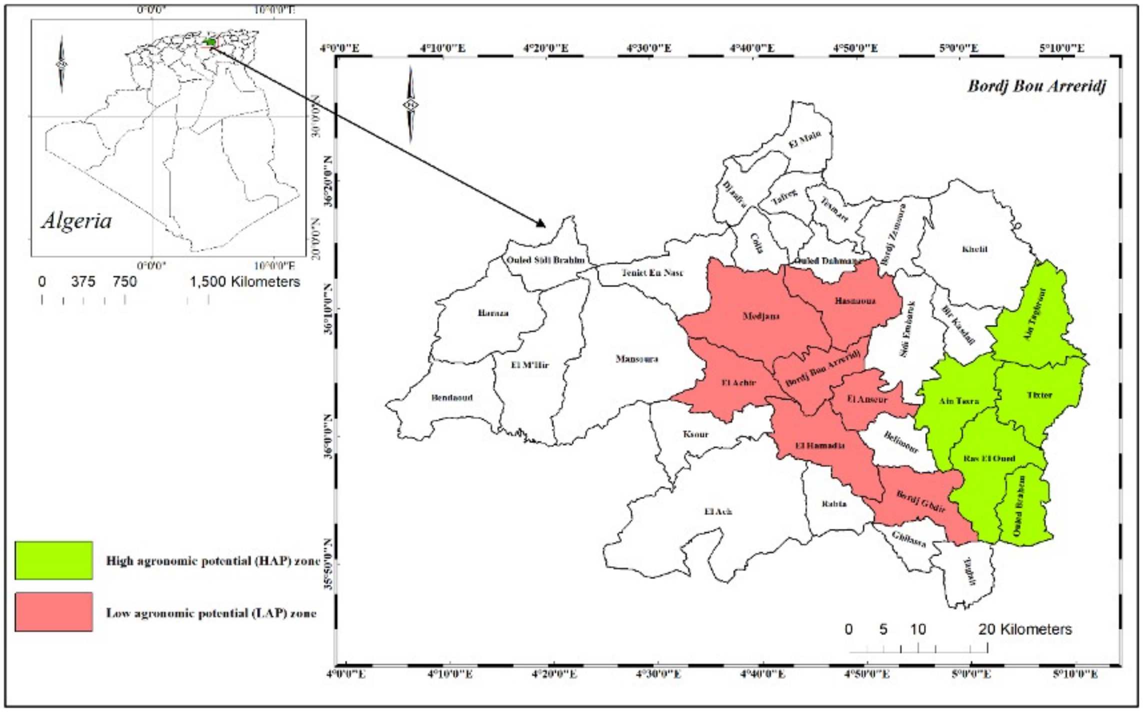

Figure 1: Study area localization and zones

Statistical Analysis

Descriptive statistics were calculated first then statistical modelling was applied to determine the factors influencing the incorporation of forage crops into cropping systems in the Bordj Bou Arreridj region. The independent variables examined as potential determinants included regional characteristics, variables describing the profiles of households and household heads, structural and equipment-related attributes of farms, livestock size expressed in livestock units (LU)-where 1 LU equals one adult dairy cow or 0.15 sheep/goats (Benoit and Veysset, 2021)- and the farming system (variables detailed in Tables 01 and 02).

In the first model, multivariate linear regression was used to highlight the factors influencing variation in the size of the forage area on the farm.

$Y = \beta 0 + \sum_{=1}^{k} \beta i X i$ Where, Y is a dependent variable that represents the size of the forage area.

In the second model, ordinal regression (ordered logistic regression) was used to highlight the factors of variation in the share of land allocated to forage in the total cultivable area.

$$logit\ (P\ (Y \leq J) = \beta 0 + \sum_{=1}^{k} \beta i X i$$

Where; P is event probability, and Y is the ordinary outcome of the share of land allocated to forage in the total cultivable area. j∈ [1, J−1] are the levels of the ordinal outcome variable (1= Low (≤ 25%), 2= edium (25%-50%), 3= High (> 50%))

In the third model, a binary logistic regression model was used to demonstrate the factors that determine the choice made by farmers between forage crops based only on grasses or forage crops that combine grasses and legumes.

$$ln\,(P/1-P) \;=\; \beta 0 \;+ \textstyle\sum_{=1}^{k} \beta iXi$$

Where; P is the vent probability of binary choices (0 or 1) between forage crops based only on grasses (0) or that combine grasses and legumes (1).

In these three models, ∑βiXi = β1X1 +…+ βkXk, where X1…Xk are independent variables, β0 is the intercept, and βi is the slope associated with the ith independent variable. To improve the precision of regression coefficient estimation, a multicollinearity test was performed by assessing variance inflation factors (VIFs). Predictors with large VIFs (> 5) were excluded from the analysis (Akinwande et al., 2015). All independent variables were tested at 1% and 5% significance levels to determine the significance of each variable. However, variables at the 10% significance level are also reported in the result. All statistics were performed with IBM SPSS 27 statistical software.

Results

Household and farms characteristics

In the Bordj Bou Arreridj region, the average age of forage producers was 57.5±13.3 years. The average age of the farm managers was very similar between the two study areas. These heads have considerable farming experience, with an average of more than 30 years. On average, three family members were involved in agricultural activities per household, with a slight advantage for households located in the high agronomic potential (HAP) zone. The exploited farmland is relatively vast, averaging 55 hectares per farm, but with a notable disparity between households. Farms in the HAP zone have a relatively larger farmland (66.0±71.7 ha). As regards livestock, agricultural households in the Bordj Bou Arreridj region have on average 10.5±11.9 livestock unite (LU) of cattle and 12.7±14.7 LU of sheep (01 LU = 01 adult dairy cow or 0,15 sheep/goat (Benoit and Veysset, 2021)). Farms in the HAP zone had a relatively higher number of cattle (12.0±13.2 LU) compared to the LAP zone (8.6±9.8 LU). Goats and horses made up a significant proportion of the surveyed farms, but their numbers were still relatively small compared to sheep and cattle (Table 1). Over 40% of the surveyed farmers were illiterate, and the frequency of farmers with no access to formal education was more pronounced in farming households located in HAP (50.0% of illiterates in the HAP zone vs. 35.7% in the LAP). More than 20% of the farmers generate off-farm income, with slightly higher numbers in the high agronomic potential zone. Less than 20% of farmers have received agricultural training, but over 50% have access to agricultural extensions. More than 20% of farm managers use social networks, and access to extension services and social networks differentiates farmers in the LAP zone.

Approximately 15% of farmers had no access to irrigation water, with a significantly higher incidence in the LPA zone (23.8%). Almost 60% of the farmers have water storage ponds, although they are slightly less common on farms in the LAP zone. While more than 60% of farms in the study area have permanent access to irrigation water, only 33% of farms in the LAP region enjoy this privilege, in contrast to 85.7% of the households in the HAP region. Similarly, 80% of the farms were equipped with irrigation equipment, with a higher frequency of farms in the HAP region (89.3%). More than 90% of farmers have tillage and seeding equipment, and over 60% possess forage-harvesting machinery. Fertilization and crop protection equipment are present on approximately 35% of farms, with HAP farms generally having better equipment than those in the LAP region. Forage transport equipment is present in more than 70% of farms. Salaried employees were employed on 25% of the farms surveyed, and this type of employment was more common on farms in the HAP zone (30.8% compared to 15.4% of farms in the LAP region). In addition, more than 40% of holdings in the region have a strategy of renting out agricultural land, and this practice is slightly more pronounced in the HAP zone (Table 2).

Table 1. Quantitative households and farms characteristics

Household and farms characteristics	HAP zone N= 56	LAP zone N=42	Overall N=98
Household head age (Years)	58.0 ±13.4	56.7 ±13.3	57.5 ±13.3
Farming experience (Years)	32.4 ±14.7	33.1 ±12.5	32.7 ±13.7
Family labor size (Person)	3.2 ±1.8	2.6 ±1.4	2.9 ±1.6
Exploited farmland size (ha)	66.0 ±71.7	39.4 ±39.4	54.6 ±61.2
Cattle livestock size (LU)	12.0 ±13.2	8.6 ±9.8	10.5 ±11.9
Sheep livestock size (LU)	12.9 ±13.7	12.4 ±16.1	12.7 ±14.7
Goats livestock size (LU)	1.4 ±2.3	1.0 ±1.7	1.2 ±2.0
Equine livestock size (LU)	0.9 ±1.6	0.1 ±0.4	0.5 ±1.3

Values represent mean± SE. HAP: high agronomic potential, LAP : Low agronomic potential , LU : livestock unite

Table 2. Qualitative households and farms characteristic

HOUSEHOLDS AND FARMS CHARACTERISTICS	MODALITIES	HAP ZONE N= 56	LAP ZONE N=42	OVERALL N=98
Household head education level	Illiterate	50.0%	35.7%	43.9%
	Basic	3.6%	19.0%	10.2%
	Secondary	39.3%	33.3%	36.7%
	University	7.1%	11.9%	9.2%
Extra-agricultural income	Yes	23.2%	19.0%	21.4%
	No	76.8%	81.0%	78.6%
Agricultural training	Yes	17.9%	16.7%	17.3%
	No	82.1%	83.3%	82.7%
Access to extension	Yes	46.4%	64.3%	54.1%
	No	53.6%	35.7%	45.9%
Access to social network	Yes	19.6%	26.2%	22.4%
	No	80.4%	73.8%	77.6%
Access to irrigation water	Without irrigation	8.9%	23.8%	15.3%
	Dam	1.8%	4.8%	3.1%
	River	0.0%	4.8%	2.0%
	Drilled well	67.9%	54.8%	62.2%
	Traditional well	21.4%	11.9%	17.3%
Water storage pond	Yes	67.9%	47.6%	59.2%
	No	32.1%	52.4%	40.8%
Permanent availability of irrigation water	Yes	85.7%	33.3%	63.3%
	No	14.3%	66.7%	36.7%
Irrigation equipment	Yes	89.3%	69.0%	80.6%
	No	10.7%	31.0%	19.4%
Tillage and seeding equipment	Yes	94.6%	88.1%	91.8%
	No	5.4%	11.9%	8.2%
Harvesting equipment	Yes	58.9%	61.9%	60.2%
	No	41.1%	38.1%	39.8%
Fertilization equipment	Yes	44.6%	26.2%	36.7%
	No	55.4%	73.8%	63.3%
Crop protection equipment	Yes	44.6%	23.8%	35.7%
	No	55.4%	76.2%	64.3%
Transport equipment	Yes	76.8%	66.7%	72.4%
	No	23.2%	33.3%	27.6%
Salaried labor	Yes	30.8%	15.4%	24.2%
	No	69.2%	84.6%	75.8%
Farmland rent-in	Yes	62.5%	54.8%	40.8%
	No	37.5%	45.2%	59.2%

Forage crops status

Area under forage crops and share of land allocated to forage

In the cropping systems of the Bordj Bou Arreridj region, farmers cultivated forage plots with an average size of 4.9 ± 4.2 ha. Compared to the farms in the LAP region, which have an average of 3.9 ± 3.8 ha, the farms in the HAP region have larger forage areas, with an average of 5.7 ± 4.4 ha. In the entire research area, approximately 40% of the surveyed farms cultivated more than 05 ha of improved forage. In the LAP region, 28.6% of farms did not cultivated more than 01 ha of improved forage (Table 3). In terms of the proportion of the arable area devoted to forage, the surveyed farmers use approximately 1/5 of their arable area. The allocation of arable land to forage was slightly lower in the LAP region (18% of arable land) than in the HAP region (23% of arable land). More than 70% of farmers use a maximum of 25% of their arable land for forage crops, whereas less than 10% use more than 1/2 of their arable land for forage crops. This category of farmers was even smaller in the LAP region (4.8%) than in the HAP region (10.7%) (Table 3).

Table 3. Area under forage crops and share of land allocated to forage

Forge crops variables	Modalities	HAP zone N= 56	LAP zone N=42	Overall N=98
Area under forage crops (ha)	≤ 1 ha	1.8%	28.6%	13,3%
	1-5 ha	51.8%	38.1%	45,9%
	> 5 ha	46.4%	33.3%	40,8%
	Mean± SE	5.7 ±4.4 ha	3.9 ±3.8 ha	4.9 ±4.2 ha
Share of land allocated to forage in the total cultivable area (%)	≤ 25%	73.2%	71.4%	72,4%
	25%-50%	16.1%	23.8%	19,4%
	> 50%	10.7%	4.8%	8,2%
	Total %	23.0 %	18.0 %	21.0 %

HAP: High agronomic potential, LAP: Low agronomic potential

Cultivated improved forage species

More than 70% of farmers cultivate barley, and nearly 55% grow oats for livestock feed. The incidence of farmers growing sorghum was approximately 21.5%. Notably, this percentage was higher in the HAP zone (30.4%) than among farmers in the LAP zone (9.5%). Corn grew as forage in 20.4% of the farms surveyed, with a frequency of 26.8% in the HAP region and almost 12% in the LAP region. Triticale is grown on one farm, whereas barley-oats are intercropped approximately on 7% of the farms. Almost 84% of farms did not include any forage legume species in their cropping systems. Approximately 13% of farms grow multi-year alfalfa, and this proportion is slightly higher in LAP (16.7%). A small proportion of the farmers grew vetches (2%) and beans (1%) (Table 4). Notably, during the crop year, farmers usually grow one forage grass in monoculture or many forage grasses in successive, mixed, and intercropping, but no more than one forage legume species in annual or perennial mixed cropping. Intercropping between grass and legumes was not recorded among the farmers in the study area.

Table 4. Cultivated forage crops species

FORAGE CROP	FORAGE SPECIES	HAP ZONE N= 56	LAP ZONE N=42	OVERALL N=98
Forage grass	Without forage grasses	0.0%	2.4%	0.0%
	Barly (*Hordeum vulgare L.*)	73.2%	71.4%	72.4%
	Oats (*Avena sativa L.*)	51.8%	57.1%	54.1%
	Sorghum (*Sorghum bicolor L.*)	30.4%	9.5%	21.4%
	Corn (*Zea mays L.*)	26.8%	11.9%	20.4%
	Triticale (×*Triticosecale Wittmack*)	1.8%	0.0%	1.0%
	Barly-Oats intercropping mixture	10.7%	2.4%	7.1%
Forage legumes	Without legumes forages	85.7%	81.0%	83.7%
	Alfalfa (*Medicago sativa L.*)	10.7%	16.7%	13.3%
	Vetch *(Vicia sativa L.),*	1.8%	2.4%	2.0%
	Faba bean (*Vicia faba L.*)	1.8%	0.0%	1.0%

Determinants of pattern of improved forages adoption

Determinants of area under forage crops

The analysis of the factors determining the area under forage crops on farms in the Bordj Bou Arreridj region indicates that exploited farmland size and the size of the sheep flock are the most significant determinants ($p < 0.001$) of farmers' decisions. Access to irrigation water also emerged as a significant factor ($p \leq 0.05$), whereas the educational level of the household head demonstrates a potentially significant impact ($p \leq 0.1$). All the significant variables exhibited a positive effect on the area allocated to forage crops. Other factors introduced in the model (variables in Tables 01 and 02) were not statistically significant and were consequently excluded from the final model. The resulting model was highly significant ($p <0.001$), with a high adjusted coefficient of determination (R^2) of 0.77 (Table 5).

Table 5. Significant determinants of the area under forage crops

FACTOR	B	ES	WALD	*P-VALUE*
Exploited farmland size	0.02	0.006	4.11	<0.001
Sheep livestock size	0.11	0.02	4.33	<0.001
Access to irrigation water	0.48	0.19	2.48	0.015
Household head education level	0.46	0.24	1.88	0.063

Model signification : ≤0.001, R^2=0.78 , Adjusted R^2=0.77

Determinants of share of land allocated to forage in the cultivable area

The size of exploited farmland exhibited a significant and negative influence on the allocation of forage land within the total cultivated area ($p \leq 0.01$). The size of the family labor force, the presence or absence of a water storage pond on the farm, the involvement of the head of the household in a social network, and the utilization of rented farmland all demonstrated a significant influence ($p \leq 0.05$) on the management strategy regarding the proportion of land devoted to forage crops. The availability of permanent irrigation water also appeared to have a potentially significant influence ($p \leq 0.1$). The other variables tested (Tables 1 and 2) were not significant and were excluded from the final model. The resulting model is highly significant, with a well-accepted coefficient of determination (Cox and Snell $R^2 = 0.41$ and Nagelkerke $R^2 = 0.54$) (Table 6).

Table 6. Significant determinants of the share of land allocated to forage in the cultivable area

FACTOR	B	ES	WALD	*P-VALUE*
Exploited farmland size	-0.05	0.02	7.03	0.008
Family labor size	-0.72	0.28	6.34	0.011
Water storage pond	2.62	1.01	5.68	0.017
Access to social network	2.85	1.31	4.76	0.029
Farmland rent-in	2.14	1.09	3.83	0.049
Permanent availability of irrigation water	2.58	1.49	2.99	0.084

Model signification: ≤0,001, Cox and Snell R^2 =0.41, Nagelkerke R^2 =0.54

Determinants of cultivated forage crops

Regarding the decision made by farmers in the study area between selecting a forage system comprised exclusively of improved grasses or a forage system that combines improved grasses with forage legumes, the empirical model demonstrates that this choice is multifaceted, influenced by various contributing factors. The most significant determinant was access to social networks by household heads ($p \leq 0.01$). Other factors, such as the size of the sheep herd, the presence of transport and phytosanitary equipment on the farm, the permanent availability of irrigation water, and access of the head of the household to agricultural training, all had a significant impact on farmers' choices ($p \leq 0.05$). Additional factors may also have a significant influence on these technical decisions ($p \leq 0.1$). These include the presence of tillage and seeding equipment, farmers' access to current agricultural techniques through agricultural extension services, the presence of irrigation equipment, and the size of cattle livestock. Other factors did not significantly affect the types of forage crops chosen by farmers. The resulting model is highly significant and widely accepted. The resulting model is highly significant, with a well-accepted coefficient of determination (Cox and Snell $R^2 = 0.38$ and Nagelkerke $R^2 = 0.58$). (Table 7).

Table 7. Significant determinants of cultivated forage crops

FACTOR	B	ES	WALD	*P-VALUE*
Access to social network	3.07	1.12	7.53	0.006
Sheep livestock size	0.07	0.03	5.32	0.021
Transport equipment	3.25	1.50	4.69	0.030
Permanent availability of irrigation water	3.06	1.48	4.29	0.038
Agricultural training	2.34	1.14	4.20	0.040
Crop protection equipment	3.75	1.91	3.87	0.049
Tillage and seeding equipment	4.01	2.08	3.71	0.054
Access to extension	2.05	1.14	3.23	0.072
Irrigation equipment	4.50	2.58	3.04	0.081
Cattle livestock size	0.07	0.04	3.00	0.083

Model signification : ≤0.001,Cox and Snell R^2 =0.34, Nagelkerke R^2 =0.58

Constraints related to improved forage development

Farmers have reported several constraints to the development of improved forages crops. In the LAP zone, which is characterized by less precipitation, the availability of irrigation water is a major constraint to the cultivation of improved forage crops, whereas in the HAP zone, this is less of a concern for farmers. Farmland size is also a significant constraint for a substantial proportion of farmers, particularly those who rent or have limited agricultural land, especially in the HAP zone. For many farmers, particularly in the HAP region, the cost of electricity, which is utilized as energy for irrigation, is a source of difficulty in establishing irrigated forage crops. Conversely, in the LAP, farmers note that the cost of using chemical fertilizers to improve forage is relatively high, which impedes the integration of forage into their farming systems. A small number of farmers indicated that farm equipment was also an obstacle to forage development, especially given the depreciation of old farm equipment and the cost of acquiring new equipment (Figure 2).

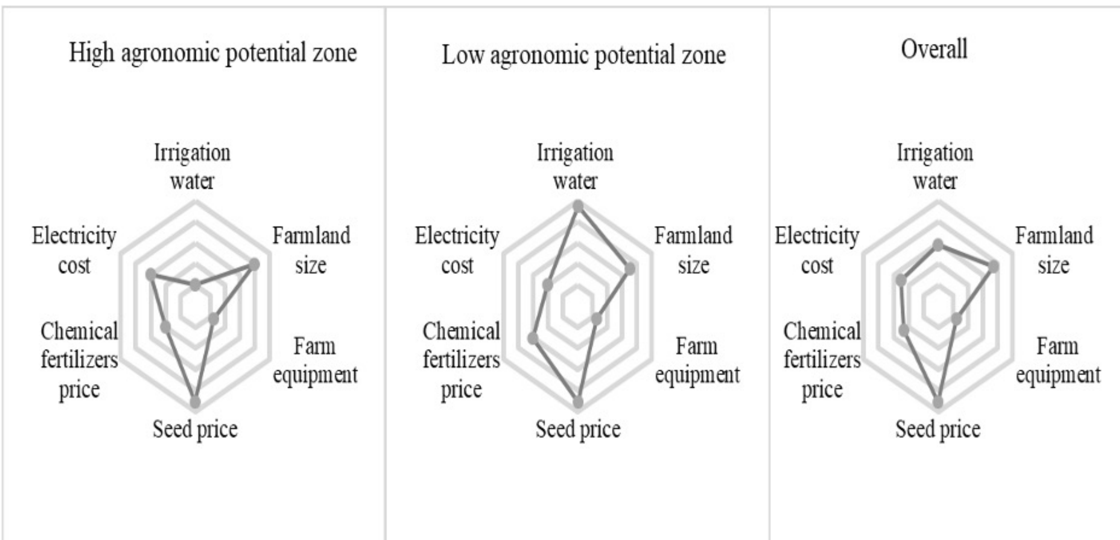

Figure 2: Constraints related to the development of improved forage

Discussion

The average forage area found in our study is around 05 ha/farm, with over 50% of farmers having forage areas between 02 and 05 ha. The relative superiority of forage areas in the HAP zone compared to the LAP zone is partly due to the agro-pedoclimatics characteristics (soil quality and rainfall) of this zone. In the Setif region, adjacent to our study area, forage areas vary from 01 to 02 ha on livestock farms (Semara et al., 2013). In the province of Blida in central Algeria, dairy cattle farmers allocated an average of 05 ha to forage production (Sofia et al., 2023) and in Tizi Ouzou region in northern Algeria, dairy cattle farms cultivate an average of 09 ha of forage per farm (Bouzida et al, 2010). In Tunisian dairy farms, forage area varies from 0.5 ha to 230 ha, depending on the production system (Amamou et al., 2018). In the Ethiopian highlands, about 50% of farms produced forage on an average area of 0.2 ha per farm (Gebremedhin et al., 2003) and in the arid and semi-arid lands of Tharaka Nithi County, Kenya, The results further indicated that only 1% of farmers grew forage on a piece of land between 0.4 and 1.2 ha (Musalia et al., 2016). Tis underscores the significant influence of agro-pedoclimatic conditions, such as soil quality and rainfall, on the allocation of forage crop areas. In regions with higher agronomic potential, forage areas are larger, reflecting better environmental conditions that support agricultural development. Additionally, comparisons across regional and international contexts highlight the variability in forage land use, shaped by both ecological and socio-economic factors. These findings suggest that targeted interventions and region-specific strategies are crucial to optimizing forage crop integration, particularly in areas with limited agronomic potential.

On average, 20% of farmland is used to grow forage crops. However, less than 10% of farmers reserve more than 50% of their farmland for forage crops. Abdeldjelil et al., (2013) found that 60% of farms in the Constantine region (more advantageous region for agriculture) allocated less than 50% of their farmland to forage production. Equivalent of 65 % of the exploited farmland is allocate to forges crops in in dairy cattle of central of Algeria (Ghozlane et al., 2021). In the irrigated perimeter of Tadla in Morocco and in dairy cattle farms, the share of forage in the total farmed area varies from 6 to 46% and can be explained by the production system (Sraïri et al., 2008). In India, in the states of Haryana and Rajasthan, forage occupies 30% of the cultivated area and in Pakistan, forage accounts for 15% of the cultivated area in the province of Punjab (Devendra & Thomas, 2002). In our context, the main forage crops grown are green barley, oats, maize, sorghum and alfalfa. Barley and oats are the forage crops most integrated into the cropping system, reflecting the cereal vocation of the region. These species are the same forage species grown in dairy cattle of central of Algeria (Ghozlane et al., 2021), in the semi-arid regions of Tunisia (Mechri et al., 2016) and Morocco (Sidikou et al., 2023). In the north of Italy, the most cultivated forages by livestock farmer are, Alfalfa , corn silage , Ryegrass , Sorghum (Bellingeri et al., 2019). Alfalfa, sainfoin, corn and vetch are the most commonly produced forages in Turkey (Cevher & Altunkaynak, 2020; Mustafa & Yolcu, 2021). In Asian countries such as India and Pakistan; maize, sorghum, bersim, alfalfa, rapeseed and oats are cultivated as improved forages (Devendra & Thomas 2002; Ul-Allah et al., 2014). However, in temperate and tropical countries, the diversity of plant species used as forages is very high (Klein et al., 2014). The allocation of farmland to forage crops is shaped by agro-ecological conditions, livestock's role within production systems, and farmers' agro-economic priorities. In our study area, the proportion of land allocated to forage crops is influenced by the higher profitability of other agricultural activities such commercial cereal crop. In some cases, when water resources are available, farmers may prefer activities like market gardening and arboriculture. This underscores the need for integrated farming strategies that balance crop and livestock production to ensure sustainability and diversification. The first key observation in our context is that improved forage species such as maize, alfalfa, and sorghum are consistently cultivated across regions, demonstrating high adaptability of this forages species to different environments. These species satisfy the yield requirements of livestock farmers in various parts of the world, from Algeria and Morocco to Pakistan and India.

The integration of improved forages into cropping systems is influenced by a complex interplay of structural, resource-based, and socio-economic factors that vary across regions. Structural factors such as farmland size, livestock size, access to irrigation, and labor availability significantly impact the feasibility and scale of forage adoption. For example, in Turkey, the size of the land and livestock positively influenced the production of forage crops (Cevher & Altunkaynak, 2020), while in Ethiopia and Kenya, factors like land tenure, market access, and farm size shaped the adoption process (Zekarias, 2016; Fenetahun et al., 2019). In addition to these structural factors, socio-economic elements such as education, agricultural training, and access to extension services are critical in enabling farmers to effectively adopt improved forages. These factors provide farmers with the necessary skills and knowledge, while social networks foster the exchange of resources and innovative practices, further promoting adoption. In Philippines and Kenya, farmers with access to social networks were more likely to adopt forages, as these networks facilitated the exchange of ideas and resources (Lapar & Ehui, 2004; Omollo et al., 2018). Moreover, institutional support, including policy interventions and infrastructure improvements, plays a key role in overcoming adoption barriers. In regions like Pakistan, where irrigation water shortages and high input costs hinder the widespread adoption of forages, addressing these systemic issues is essential for fostering sustainable practices (Ul-Allah et al., 2014). Therefore, the successful integration of improved forages requires a comprehensive approach that not only addresses farm-level constraints but also strengthens education, infrastructure, and institutional frameworks to ensure long-term sustainability and resilience in agricultural systems.

The constraints to expanding forage crop areas are multifaceted, and our study reflects several key challenges observed globally. Farmers identified issues such as the high cost and unavailability of seeds, lack of arable land, and limited irrigation water, along with the high input costs (electricity and fertilizers). These challenges align with those reported in other regions, including Ethiopia, where farmers face land scarcity, limited seed access, and lack of awareness (Desta, 2022; Mengistu et al., 2021), and the Philippines, where similar difficulties in seed availability and the high mortality of planted forages hinder adoption (Lapar & Ehui, 2004). Structural barriers, like inadequate irrigation infrastructure and high input costs, exacerbate the situation in Turkey and Pakistan (Balabanli et al., 2016; Ul-Allah et al., 2014). These findings point to the need for integrated strategies that can address these barriers holistically. Investments in seed distribution networks, irrigation infrastructure, and extension services are essential for overcoming these constraints. Additionally, improving farmer awareness and developing supportive policies are crucial for enhancing forage adoption.

Conclusion

This study attempts to analyze the status, determinants, and constraints of forage production on family farms in the Bordj Bou Arreridj region, revealing a diverse farmer profile and significant regional variation in farm structures. The area dedicated to fodder remains relatively small in comparison to both total farmland and livestock size. The primary forage species are grasses (green barley, oats, maize, and sorghum) and legumes (mainly alfalfa, with occasional vetches and faba beans). A variety of structural and socio-economic factors play key roles in determining the adoption of improved forage species. These include farm size, livestock size, access to irrigation, availability of family labor, and the accessibility of farm equipment. Socio-economic characteristics, such as the education level of farm managers and their access to agricultural training, extension services and socials networks, significantly influence the adoption process. This study underscores the importance of a comprehensive, region-specific approach to overcome forage adoption challenges, including high seed costs, land scarcity, limited irrigation, and high input costs.

To promote forage cultivation in semi-arid farming systems, it is critical to raise farmer awareness about its benefits such as improving livestock feed autonomy, enhancing soil productivity, promoting biodiversity, and mitigating soil erosion. Policymakers should support these practices by offering subsidies for seeds and equipment. Focusing on both the farm-level and systemic issues, targeted interventions can foster more sustainable and resilient farming systems that better cope with the challenges posed by climate change and resource limitations.

References

Abbas, K., & Abdelguerfi, A. (2005). Perspectives d’avenir de la jachère pâturée dans les zones céréalières semi-arides. *Fourrages*, *184*, 533–546.

Abbas, K., Mebarkia, A., & Mohguen, K. (2014). Performances of some fodder cultivars cultivated in pure stand or in association under semi-arid conditions of Algeria. In *Forage resources and ecosystem services provided by Mountain and Mediterranean grasslands and rangelands* (pp. 843). Zaragoza: CIHEAM/INRA/FAO/VetAgro Sup Clermont-Ferrand/Montpellier SupAgro. (Options Méditerranéennes: Série A. Séminaires Méditerranéens; No. 109). https://om.ciheam.org/ressources/om/pdf/a109/a109.pdf

Abdeldjelil, M. C., Agabou, A., Boudebza, A., Messai, A., Aimeur, F., Bensegueni, A., & Benazzouz, H. (2013). Analysis of ruminants feeding systems in some Algerian farms: Obstacle to achieve autonomy. *Options Méditerranéennes. Série A, Séminaires Méditerranéens*, *(107)*, 91–95. https://om.ciheam.org/web/controleurFrontal.php?action=afficherArticle&IDPDF=7016

Abusuwar, A. O., & Ahmed, E. O. (2010). Seasonal variability in nutritive value of ruminant diets under open grazing system in the semi-arid rangeland of Sudan (South Darfur State). *Agriculture and Biology Journal of North America, 1*(3), 243–249. https://doi.org/10.5251/ABJNA.2010.1.3.243.249

Achir, C., Annicchiarico, P., Pecetti, L., Khelifi, H. E., M'Hammedi-Bouzina, M., Abdelguerfi, A., & Laouar, M. (2020). Adaptation patterns of sixteen alfalfa (*Medicago sativa* L.) cultivars across contrasting environments of Algeria and implications for the crop improvement. *Italian Journal of Agronomy, 15*(1), 57–62. https://doi.org/10.4081/ija.2020.1578

Akinwande, M. O., Dikko, H. G., & Samson, A. (2015). Variance inflation factor: As a condition for the inclusion of suppressor variable(s) in regression analysis. *Open Journal of Statistics, 5*(7), 754–767. https://doi.org/10.4236/ojs.2015.57075

Amad, A. A., & Zentek, J. (2023). The use of *Moringa oleifera* in ruminant feeding and its contribution to climate change mitigation. *Frontiers in Animal Science, 4*, 1137562. http://doi.org/10.3389/fanim.2023.1137562

Amamou, H., Sassi, M. B., Aouadi, H., Khemiri, H., Mahouachi, M., Beckers, Y., & Hammami, H. (2018). Climate change-related risks and adaptation strategies as perceived in dairy cattle farming systems in Tunisia. *Climate Risk Management, 20*, 38–49. https://doi.org/10.1016/j.crm.2018.03.004

Annicchiarico, P. (2017). Feed legumes for truly sustainable crop-animal systems. *Italian Journal of Agronomy, 12*(2). https://doi.org/10.4081/ija.2017.880

Balabanli, C., Cirit, Y., Kayacan, S., Bıçakçı, E., & Yüksel, O. (2016). Determination of forage crops producer behaviour in agriculture; Example of Isparta Province. *Journal of Central Research Institute for Field Crops, 25*(2). https://doi.org/10.21566/tarbitderg.282817

Bellingeri, A., Cabrera, V., Gallo, A., Liang, D., & Masoero, F. (2019). A survey of dairy cattle management, crop planning, and forages cost of production in Northern Italy. *Italian Journal of Animal Science, 18*(1), 786–798. https://doi.org/10.1080/1828051X.2019.1580153

Benoit, M., & Veysset, P. (2021). Livestock unit calculation: A method based on energy needs to refine the study of livestock farming systems. *INRAE Productions Animals, 33*, 139–160. https://doi.org/10.20870/productions-animales.2021.34.2.4855

Bir, A. (2019). Stratégies d'adaptation des éleveurs bovins laitiers aux contraintes climatiques dans la région semi-aride de Sétif, Algérie. *Livestock Research for Rural Development, 31*(7). https://www.lrrd.org/lrrd31/7/moh31104.html

Birhanu, M. Y., Girma, A., & Puskur, R. (2017). Determinants of success and intensity of livestock feed technologies use in Ethiopia: Evidence from a positive deviance perspective. *Technological Forecasting and Social Change, 115*, 15–25. https://doi.org/10.1016/j.techfore.2016.09.010

Boddey, R. M., Casagrande, D. R., Homem, B. G., & Alves, B. J. (2020). Forage legumes in grass pastures in tropical Brazil and likely impacts on greenhouse gas emissions: A review. *Grass and Forage Science, 75*(4), 357–371. https://doi.org/10.1111/gfs.12498

Bouzida, S., Ghozlane, F., Allane, M., Yakhlef, H., & Abdelguerfi, A. (2010). Impact du chargement et de la diversification fourragère sur la production des vaches laitières dans la région de Tizi-Ouzou (Algérie). *Fourrages, 204*, 269–275.

Bybee-Finley, K. A., & Ryan, M. R. (2018). Advancing intercropping research and practices in industrialized agricultural landscapes. *Agriculture, 8*(6), 80. https://doi.org/10.3390/agriculture8060080

Capstaff, N. M., & Miller, A. J. (2018). Improving the yield and nutritional quality of forage crops. *Frontiers in Plant Science, 9*, 338501. https://doi.org/10.3389/fpls.2018.00535

Cevher, C., & Altunkaynak, B. (2020). Socioeconomic factors and sustainable forage crops production in Turkey Aegean Region: A multivariate modeling. *Sustainability, 12*(19), 8061. https://doi.org/10.3390/su12198061

Cheng, M., McCarl, B., & Fei, C. (2022). Climate change and livestock production: A literature review. *Atmosphere, 13*(1), 140. https://doi.org/10.3390/atmos13010140

Collins, M., Nelson, C.J., Moore, K.J., & Barnes, R. F.. (2018). *Forages Volume I: An introduction to grassland agriculture* (7th ed.). Hoboken, NJ: John Wiley & Sons.

Dagar, J. C., Ghosh, P. K., Mohanta, S. K., Singh, J. B., Vijay, D., & Kumar, R. V. (2017). Potentials for fodder production in degraded lands. In P. K. Ghosh, S. K. Mohanta, J. B. Singh, D. Vijay, R. V. Kumar, V. K. Yadav, & S. Kumar (Eds.), *Approaches towards fodder security in India* (pp. 333–364). New Delhi: Studera Press.

Davis, H., Chatzidimitriou, E., Leifert, C., & Butler, G. (2020). Evidence that forage-fed cows can enhance milk quality. *Sustainability, 12*(9), 3688. https://doi.org/10.3390/su12093688

Desta, A. G. (2022). Constraints of improved forage adoption in East Gojjam Zone, Ethiopia. *Current Agriculture Research Journal, 10*(2). http://dx.doi.org/10.12944/CARJ.10.2.07

Devendra, C., & Thomas, D. (2002). Crop–animal interactions in mixed farming systems in Asia. *Agricultural Systems, 71*(1–2), 27–40. https://doi.org/10.1016/S0308-521X (01)00034-8.

Devendra, C., & Leng, R. A. (2011). Feed resources for animals in Asia: Issues, strategies for use, intensification and integration for increased productivity. *Asian-Australasian Journal of Animal Sciences, 24*(3), 303–321. https://doi.org/10.5713/ajas.2011.r.05

Díaz de Otálora, X., Dragoni, F., Del Prado, A., Estellés, F., Wilfart, A., Krol, D., ... & Amon, B. (2022). Identification of representative dairy cattle and fodder crop production typologies at regional scale in Europe. *Agronomy for Sustainable Development, 42*(5), 94. https://doi.org/10.1007/s13593-022-00830-3

Dos Santos, N. Z., Dieckow, J., Bayer, C., Molin, R., Favaretto, N., Pauletti, V., & Piva, J. T. (2011). Forages, cover crops and related shoot and root additions in no-till rotations to C sequestration in a subtropical Ferralsol. *Soil and Tillage Research, 111*(2), 208–218. https://doi.org/10.1016/j.still.2010.10.008

Entz, M. H., Baron, V. S., Carr, P. M., Meyer, D. W., Smith, S. R. Jr., & McCaughey, W. P. (2002). Potential of forages to diversify cropping systems in the Northern Great Plains. *Agronomy Journal, 94*(2), 240–250. https://doi.org/10.2134/agronj2002.2400

Ergon, Å., Seddaiu, G., Korhonen, P., Virkajärvi, P., Bellocchi, G., Jørgensen, M., ... & Volaire, F. (2018). How can forage production in Nordic and Mediterranean Europe adapt to the challenges and opportunities arising from climate change? *European Journal of Agronomy, 92*, 97–106. https://doi.org/10.1016/j.eja.2017.09.016

Fenetahun, Y., Xu, X., & Wang, Y. (2019). Determinants of pastoral communities for adoption of forage production technology in Yabello rangeland, Southern Ethiopia. *Journal of Ecology and the Natural Environment, 11*(8). https://doi.org/10.5897/JENE2019.0771

Finch, H. J. S., Samuel, A. M., & Lane, G. P. F. (2014). Conservation of grass and forage crops. In *Lockhart & Wiseman's crop husbandry including grassland* (9th ed., pp. 513–526). Woodhead Publishing Series in Food Science, Technology and Nutrition. https://doi.org/10.1533/9781782423928.4.513

Franzluebbers, A. J., & Martin, G. (2022). Farming with forages can reconnect crop and livestock operations to enhance circularity and foster ecosystem services. *Grass and Forage Science, 77*(4), 270–281. https://doi.org/10.1111/gfs.12592

Fuglie, K., Peters, M., & Burkart, S. (2021). The extent and economic significance of cultivated forage crops in developing countries. *Frontiers in Sustainable Food Systems, 5*, 712136. https://doi.org/10.3389/fsufs.2021.712136

Gebremedhin, B., Ahmed, M., & Ehui, S. (2003). Determinants of adoption of improved forage technologies in crop–livestock mixed systems: Evidence from the highlands of Ethiopia. *Tropical Grasslands, 37*, 262–273. https://hdl.handle.net/10568/27820

Ghozlane, M., Boukhechem, S., & Bouamra, M. (2021). Feed autonomy of a few dairy cattle farms in the Mitidja Plain (Algeria). *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Veterinary Medicine, 78*(1). https://doi.org/10.15835/buasvmcn-vm:2021.0003

Gilhaus, K., & Hölzel, N. (2016). Seasonal variations of fodder quality and availability as constraints for stocking rates in year-round grazing schemes. *Agriculture, Ecosystems & Environment, 234*, 5–15. https://doi.org/10.1016/j.agee.2016.03.013

Giridhar, K., & Samireddypalle, A. (2015). Impact of climate change on forage availability for livestock. In V. Sejian, J. Gaughan, L. Baumgard, & C. Prasad (Eds.), *Climate change impact on livestock: Adaptation and mitigation* (pp. 115–129). Springer, New Delhi. https://doi.org/10.1007/978-81-322-2265-1_7

Grover, D. K., & Kumar, S. (2012). *Economics of production, processing and marketing of fodder crops in India*. Agro-Economic Research Centre, Punjab Agricultural University, Ludhiana. https://aercpau.com/assets/docs/FODDER_INDIA41.pdf

Gunasekaran, S., Bandeswaran, C., & Valli, C. (2019). Low-cost hydroponic fodder production technology for sustainable livestock farming during fodder scarcity. *Current Science, 116*(4), 526–528. https://www.jstor.org/stable/27137893

Guyader, J., Janzen, H. H., Kroebel, R., & Beauchemin, K. A. (2016). Forage use to improve environmental sustainability of ruminant production. *Journal of Animal Science, 94*(8), 3147–3158. https://doi.org/10.2527/jas.2015-0141

Harris-Coble, L., Balehegn, M., Adesogan, A. T., & Colverson, K. (2022). Gender and livestock feed research in developing countries : A review. *Agronomy Journal, 114*(1), 259–276. https://doi.org/10.1002/agj2.20875

Henzell, E. F. (2019). Contribution of forages to worldwide food production : Now and in the future. In *Proceedings of the XIV International Grassland Congress* (pp. 42–47). CRC Press. https://doi.org/10.1201/9780429303142

Junca Paredes, J. J., Florez, J. F., Enciso Valencia, K. J., Hernández Mahecha, L. M., Triana Ángel, N., & Burkart, S. (2023). Potential forage hybrid markets for enhancing sustainability and food security in East Africa. *Foods, 12*(8), 1607. https://doi.org/10.3390/foods12081607

Kadi, S. A., & Djellal, F. (2009). Autonomie alimentaire des exploitations laitières dans la région de Tizi-Ouzou, Algérie. *Livestock Research for Rural Development, 21*(12). https://lrrd.cipav.org.co/lrrd21/12/kadi21182.htm

Klein, H. D., Rippstein, G., Huguenin, J., Toutain, B., & Guerin, H. (2014). *Les cultures fourragères*. Éditions Quae. Paris, France. 264 p.

Koudahe, K., Allen, S. C., & Djaman, K. (2022). Critical review of the impact of cover crops on soil properties. *International Soil and Water Conservation Research, 10*(3), 343–354. https://doi.org/10.1016/j.iswcr.2022.03.003

Lapar, M. L. A., & Ehui, S. K. (2004). Factors affecting adoption of dual-purpose forages in the Philippine uplands. *Agricultural Systems, 81*(2), 95–114. https://doi.org/10.1016/j.agsy.2003.09.003

Mahmah, S., Mebarkia, A., & Rekik, F. (2023). A comparative study on narbon vetch and common vetch in the semi-arid region of Setif (Algeria). *Journal of Agricultural Sciences, Belgrade, 68*(3), 263–282. https://doi.org/10.2298/JAS2303263M

Makkar, H. P. S. (2012). Feed and fodder challenges for Asia and the Pacific. In V. Ahuja (Ed.), *Asian livestock: challenges, opportunities and the response. Proceedings of an international policy forum, Bangkok, Thailand, 16–17 August 2012* (pp. 81–96). FAO: Bangkok, Thailand.

Makkar, H. P. (2016). Smart livestock feeding strategies for harvesting triple gain–the desired outcomes in planet, people and profit dimensions: a developing country perspective. *Animal Production Science, 56*(3), 519–534. https://doi.org/10.1071/AN15557

Martens, J. R. T., Entz, M. H., & Wonneck, M. D. (2015). Redesigning Canadian prairie cropping systems for profitability, sustainability, and resilience. *Canadian Journal of Plant Science, 95*(6), 1049–1072. https://doi.org/10.4141/cjps-2014-173

Mebarkia, A., Bougrine, H., Badache, F., & Mahmah, S. (2020). Etude de la production et de la phénologie de dix variétés de Vesce (vicia) du réseau maghrébin dans les hautes plaines Sétifiennes (Algérie). *Fourrages, 241*, 57–64.

Mechri, M., Patil, S. B., Saidi, W., Hajri, R., Jarrahi, T., Gharbi, A., & Jedidi, N. (2016). Soil organic carbon and nitrogen status under fallow and cereal-legume species in a Tunisian semi-arid conditions. *European Journal of Earth and Environment, 3*(1).

Mefti, M., Bouzerzour, H., Francia, E., Ulrici, A., Abdelguerfi, A., Barre, P., & Pecchioni, N. (2016). Agronomic and molecular evaluation of cocksfoot and tall fescue cultivars for adaptation to an Algerian drought-prone environment. *Euphytica, 212*, 371–386. https://doi.org/10.1007/10.1007/s10681-016-1762-7

Mengistu, A., Assefa, G., Kebede, G., & Feyissa, F. (2016). Review on the evolution of forage seed production in Ethiopia: Experiences, constraints and options. *Academic Research Journal of Agricultural Science and Research, 4*(6), 231–240. https://doi.org/10.14662/ARJASR2016.023

Mengistu, A., Kebede, G., Feyissa, F., & Assefa, G. (2017). Review on major feed resources in Ethiopia: Conditions, challenges and opportunities. *Academic Research Journal of Agricultural Science and Research, 5*(3), 176–185. https://doi.org/10.14662/ARJASR2017.013

Mengistu, S., Nurfeta, A., Tolera, A., Bezabih, M., Adie, A., Wolde-Meskel, E., & Zenebe, M. (2021). Livestock production challenges and improved forage production efforts in the Damot Gale District of Wolaita Zone, Ethiopia. *Advances in Agriculture*, 1–10. https://doi.org/10.1155/2021/5553659

Morrison, R., Teufel, N., Duncan, A., & Barnes, A. (2023). An innovation systems approach to understanding forage adoption intensity in the dairy systems of Kenya and Ethiopia. *Outlook on Agriculture, 52*(4), 371–381. https://doi.org/10.1177/00307270231171712

Musalia, L. M., Odilla, G. A., Nderi, O. M., & Muleke, V. (2016). Current status of fodder production, conservation and marketing in the arid and semi-arid lands of Tharaka Nithi

County, Kenya. *African Journal of Agricultural Research, 11*(26), 2337–2347. https://doi.org/10.5897/AJAR2016.11162

Mustafa, T. A. N., & Yolcu, H. (2021). Current status of forage crops cultivation and strategies for the future in Turkey: A review. *Journal of Agricultural Sciences, 27*(2), 114–121. https://doi.org/10.15832/ankutbd.903732

Mutimura, M., Ebong, C., Rao, I. M., & Nsahlai, I. V. (2019). Seasonal variation of livestock feed resources in semi-arid and humid environments of Rwanda. *East African Agricultural and Forestry Journal, 83*(2), 137–148. https://doi.org/10.1080/00128325.2019.1603578

Nhundu, T., Mutandwa, E., Stark, J., Chamboko, T., & Vambe, A. T. (2023). Determinants of smallholder livestock farmers' adoption decisions of improved fodder technologies in Insiza District. *African Journal of Science, Technology, Innovation and Development, 15*(7), 805–816. https://doi.org/10.1080/20421338.2023.2196199

Njarui, D. M., Gatheru, M., Gichangi, E. M., Nyambati, E. M., Ondiko, C. N., & Ndungu-Magiroi, K. W. (2017). Determinants of forage adoption and production niches among smallholder farmers in Kenya. *African Journal of Range & Forage Science, 34*(3), 157–166. https://www.ajol.info/index.php/ajrfs/article/view/163037

Notenbaert, A. M., Douxchamps, S., Villegas, D. M., Arango, J., Paul, B. K., Burkart, S., ... & Peters, M. (2021). Tapping into the environmental co-benefits of improved tropical forages for an agroecological transformation of livestock production systems. *Frontiers in Sustainable Food Systems, 5*, 742842. https://doi.org/10.3389/fsufs.2021.742842

Omollo, E. O., Wasonga, O. V., Elhadi, M. Y., & Mnene, W. N. (2018). Determinants of pastoral and agro-pastoral households' participation in fodder production in Makueni and Kajiado Counties, Kenya. *Pastoralism, 8*, 1–10. https://doi.org/10.1186/s13570-018-0113-9

Partha, B., & Nagaratna, B. (2016). Socio-economic profile of perennial fodder growers and the constraints faced by them in cultivation. *Journal of Farm Sciences, 29*(4), 466–469

Paul, B. K. (2019). *At a crossroads: Potential impacts and trade-offs of improved livestock feeding and forages in smallholder-farming systems of East Africa* (PhD thesis). Wageningen University, Wageningen, the Netherlands, 257 pages. https://doi.org/10.18174/497381

Paul, B. K., Groot, J. C., Maass, B. L., Notenbaert, A. M., Herrero, M., & Tittonell, P. A. (2020). Improved feeding and forages at a crossroads: Farming systems approaches for sustainable livestock development in East Africa. *Outlook on Agriculture, 49*(1), 13–20. https://doi.org/10.1177/0030727020906170

Peters, M., Herrero, M., Fisher, M., Erb, K. H., Rao, I., Subbarao, G. V., ... & Searchinger, T. (2013). Challenges and opportunities for improving eco-efficiency of tropical forage-based systems to mitigate greenhouse gas emissions. *Tropical Grasslands-Forrajes Tropicales, 1*(2), 156–167. https://doi.org/10.17138/tgft

Picasso, V. D., Berti, M., Cassida, K., Collier, S., Fang, D., Finan, A., ... & Williams, C. (2022). Diverse perennial circular forage systems are needed to foster resilience, ecosystem services, and socioeconomic benefits in agricultural landscapes. *Grassland Research, 1*(2), 123–130. https://doi.org/10.1002/glr2.12020

Pushpanjali, R. K. S., Samuel, J., Pankaj, P. K., Reddy, A. G. K., Rohit, J., & Reddy, K. S. (2022). Fodder grass strips for soil conservation and soil health. *Chemistry Proceedings, 10*(1), 58. https://doi.org/10.3390/IOCAG2022-12189

Ramesh, P., Triveni, G., Sharma, G. R. K., Reddy, Y. R., & Singh, R. P. (2021). Socio-economic profile and constraints faced by dairy farmers in utilisation of fodder development scheme in Srikakulam district of Andhra Pradesh. *Indian Journal of Extension Education, 57*(3), 196–200.

https://doi.org/10.5958/2454-552X.2021.00123.7

Rao, I., Peters, M., Castro, A., Schultze-Kraft, R., White, D. S., Fisher, M., Miles, J., Lascano, C. E., Blümmel, M., Bungenstab, D., et al. (2015). Livestock Plus -The sustainable intensification of forage-based agricultural systems to improve livelihoods and ecosystem services in the tropics. *Tropical Grasslands-Forrajes Tropicales, 3*, 59–82. https://hdl.handle.net/10568/68840

Rathod, P. (2017). Attitude of dairy farmers towards cultivation of green fodder crops in Bidar District of Karnataka. *Indian Journal of Veterinary Sciences and Biotechnology, 12*(3), 152–156.

Salo, S., Tadesse, G., & Haylemeskel, D. (2017). Survey on constraints of improved forage adoption in Anelemo Woreda, Hadiya Zone, Ethiopia. *Agricultural Research and Technology: Open Access Journal, 12*(2).

Semara, L., Mouffok, C., & Madani, T. (2013). Livestock farming systems and cattle production orientation in eastern high plains of Algeria, cattle farming system in Algerian semi-arid region. *International Journal of Agriculture Management and Development, 3*(4), 237–244.

Senoussi, A., & Behir, T. (2010). Étude des disponibilités des aliments de bétail dans les régions sahariennes. Cas de la région du Souf. *Revue du Chercheur, 08*. http://revues.univ-ouargla.dz/images/banners/ASTimages/elbahithimages/BAHIN08/R0814.pdf

Shit, N. (2019). Hydroponic fodder production: An alternative technology for sustainable livestock production in India. *Exploratory Animal & Medical Research, 9*(2). https://www.cabidigitallibrary.org/doi/pdf/10.5555/20203435611

Sidikou, A. A. H., Drissi, S., Bouaziz, A., Dhassi, K., Amlal, F., Darrhal, N., ... & Houssa, A. A. (2023). Productivity, quality, and nutrient uptake of intensive forage crop rotations based on corn in sandy soil (northern Morocco). *Sains Tanah: Journal of Soil Science and Agroclimatology, 20*(1), 32–42.

Singh, D. N., Bohra, J. S., Tyagi, V., Singh, T., Banjara, T. R., & Gupta, G. (2022). A review of India's fodder production status and opportunities. *Grass and Forage Science, 77*(1), 1–10. https://doi.org/10.1111/gfs.12561

Singh, K. M., Meena, M. S., & Kumar, A. (2012). An economic view to forage and fodder production in eastern India. http://dx.doi.org/10.2139/ssrn.2030697

Sofia, K., Sabrine, A. C. F., Nabil, A., Rofia, B., Mohamed, B., Nabil, B., & Chafia, C. (2023). Situation of forage crops intended for feeding dairy cattle in some breeding farms in the Wilaya of Blida (Algeria). *Agricultural Science Digest, 43*(6), 870–876. https://doi.org/10.18805/ag.DF-423

Sraïri, M. T., Touzani, I., Le Gal, P. Y., & Kuper, M. (2008). In Kuper, M., & Zaïri, A. A. (Eds.), *Économies d'eau en systèmes irrigués au Maghreb: Actes du 3e Atelier Régional*, 4–8 juin 2007, Nabeul, Tunisie. Montpellier: CIRAD.

Thornton, P. K. (2010). Livestock production: Recent trends, future prospects. *Philosophical Transactions of the Royal Society B: Biological Sciences, 365*(1554), 2853–2867.

Tionyele, F., Lankpitouo, J. P., Issouf, T., Souleymane, O., & Baba, O. (2022). Determinants of the adoption of forage crops in the rural municipality of Koumbia in Burkina Faso. *International Journal of Agricultural Economics, 7*(3), 140–145. https://doi.org/10.11648/j.ijae.20220703.15

Tlahig, S., Neji, M., Atoui, A., Seddik, M., Dbara, M., Yahia, H., ... & Loumerem, M. (2024). Genetic and seasonal variation in forage quality of lucerne (*Medicago sativa* L.) for resilience to climate change in arid environments. *Journal of Agriculture and Food Research, 15*, 100986. https://doi.org/10.1016/j.jafr.2024.100986

Tulu, D., Gadissa, S., Hundessa, F., & Kebede, E. (2023). Contribution of climate-smart forage and fodder production for sustainable livestock production and environment: Lessons and challenges from Ethiopia. *Advances in Agriculture, 2023*. https://doi.org/10.1155/2023/8067776

Turinawe, A., Mugisha, J., & Kabirizi, J. (2012). Socio-economic evaluation of improved forage technologies in smallholder dairy cattle farming systems in Uganda. *Journal of Agricultural Science, 4*(3), 169–174. http://dx.doi.org/10.5539/jas.v4n3p163

Ul-Allah, S., Khan, A. A., Burkert, A., & Wachendorf, M. (2014). Socio-economic aspects of fodder production in urban and peri-urban areas of Faisalabad. *Pakistan Journal of Agricultural Sciences, 51*(2).

Vinita, S. S., Bala, A., Singh, U., Kumar, K., & Gautam, A. M. (2023). Socioeconomic profile of fodder production and feeding practices of dairy farmers: A study in Jind, Charkhidadri and Yamunanagar districts of Haryana. *International Journal of Statistics and Applied Mathematics, SP-8*(4), 193–197.

Zekarias, B. (2016). Determinants of improved forages adoption in Doyogena district of Kembata Tembaro zone, in Southern Nations, Nationalities Regional State, Ethiopia. *Global Journal of Science Frontier Research: Agriculture and Veterinary, 16*(3).

Zirmi-Zembri, N., & Kadi, S. A. (2016). Valeur nutritive des principales ressources fourragères utilisées en Algérie. 1-Les fourrages naturels herbacés. *Livestock Research for Rural Development, 28*(8). https://www.lrrd.org/lrrd28/8/zemb28145.html