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Research article

Evaluation of selected fodder species for alley cropping systems

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Abstract

This study examined various shrub species integrated into field crops (wheat, vetch, barley), including leguminous varieties (*Medicago arborea, Colutea istria, Coronilla glauca*), *Atriplex* species (*A. canescens, A. nummularia, A. undulata*), and *Opuntia ficus-indica*. It assessed their suitability based on forage production, quality, direct browsing, seasonal suitability for direct browsing and soil fertility. *Atriplex* species demonstrated higher suitability indexes. While leguminous species enhanced soil nutrient status, their low initial biomass productivity limited suitability for livestock forage. *Opuntia ficus-indica*, with a lower suitability index, was deemed unsuitable for direct browsing, as it was primarily a cut-and-carry crop. Therefore, the successful implementation of alley cropping systems requires a careful balance and analysis of shrub species that not only provide ample forage biomass support but also direct browsing and contribute to enhanced soil conditions for crop growth. This approach holds promise for sustainable and productive farming practices.

Keywords*:* Alley cropping, *Atriplex*, Biomass, Leguminous forage, Suitability index

Introduction

The world's population is expected to grow to 9.8 billion by 2050 and 11.2 billion by 2100, which leads to an increased demand for animal products (Godfray *et al.,* 2010; Pison, 2019). Livestock play an important in providing food and livelihoods. An increase in the consumption of livestock products is predicted to play a crucial role in addressing food security concerns. Projections indicate that global demand for meat and milk between 2005 and 2050 will increase by 57% and 48%, respectively (Alexandratos and Bruinsma, 2012). This demand is constrained by limited resources and the impact of climate change (Cheng *et al.,* 2022) resulting in challenges when it comes to providing animal feed. It is estimated that livestock consume about six billion tons of feed annually. Most is not suitable for human consumption (Mottet *et al.,* 2017). As the demand continues to grow, there will be a need for 11% to 17% of feed that can be consumed by humans and a 6% to 15% increase in feed for livestock. Climate change further exacerbates the situation by affecting both livestock and feed production (Mottet *et al.,* 2017). The ability to meet the demands for livestock feed remains uncertain due to climate challenges and competition for land and water resources (Peters *et al.,* 2014). Additionally, it is important to consider how feed production impacts the sustainability of livestock systems (Baltenweck *et al.,* 2020; FAO, 2018). Navigating the challenges and opportunities of planning livestock production and addressing feed requirements is of the utmost importance.

Agroforestry, characterized by the deliberate integration of trees or shrubs into crop and animal production systems, is a promising approach to addressing challenges in livestock keeping (Poch and Simonetti, 2013). This practice holds significant potential to improve both the provision and quality of animal feed. Notably, agroforestry systems offer a range of benefits, such as mitigating greenhouse gas emissions from the livestock sector, bolstering livestock resilience against the impacts of climate change, elevating the nutritional quality of animal-derived food, and several social advantages (Lasco *et al.,* 2014). Agroforestry encompasses five primary practices: alley cropping, forest farming, riparian forest buffers, silvopasture, and windbreaks (USDA, 2021). Among these, alley cropping takes center stage as a widely adopted agroforestry approach. It involves the integration of trees and crops within

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agricultural landscapes and stands as one of the most common agroforestry practices worldwide. It is typically characterized by widely spaced rows of trees or shrubs with intercropped agricultural crops in the intervening alleys, fostering dynamic interactions between these components (Zamora *et al.,* 2019). The combination of tree and crop species can vary widely, resulting in diverse forms of alley cropping globally (Mosquera-Losada *et al.,* 2009). Initially conceived for crop production, alley cropping has evolved to offer significant potential for integrating crop and livestock production, primarily through the provision of high-quality fodder that enriches diets and enables planned grazed fallows within cropping cycles (Koocheki and Gliessman, 2005). However, effective management is essential to mitigate competition between trees and crops that can adversely impact crop yields.

Selecting appropriate trees, shrubs and crops is a crucial decision, demanding comprehensive control of ecological and agronomic variables. Scientific research underscores the significance of considering species compatibility with local climate, soil characteristics, and livestock preferences (d'Hervilly *et al.,* 2022; Lovell *et al.,* 2021). Prioritizing plants that offer nutritious forage and exhibit traits like tolerance to repeated defoliation, regrowth capacity, and resistance to browsing or trampling is essential (Carter *et al*., 1998). Integrating leguminous shrubs and trees, which facilitate soil fertility enhancement through nitrogen fixation (Alamu *et al.,* 2023; Chauhan *et al.,* 2014), stands as a valuable practice in sustainable alley cropping systems.

In semi-arid conditions, an essential consideration for successful forage production within an alley cropping system is the sustainability of feed provision for livestock. Numerous forage shrub species of high nutritive value can be employed (Chaturvedi *et al.,* 2016). Typically, feeding aligns with the timing of high nutritional value forage shrubs when crop aftermath grazing may not be suitable. In this system, there is potential for livestock to graze on crop residues during the dry season, supplemented by tree fodder to enhance their diet. Ultimately, an evidence-based approach informed by local conditions and existing research findings will be instrumental in ensuring the success of alley cropping initiatives that incorporate direct grazing. This study aimed to assess the viability of shrub species as potential hedgerow components within Mediterranean alley cropping systems. The assessment involved developing a suitability index based on aboveground biomass production and best timing for use by animals.

Materials and Methods

Site description: A field experiment was conducted at Muchaqqer Research Station in the region of East Jordan (altitude approximately 794 m, mean annual rainfall is 350 mm), rain falls mostly between October and April. The soil is classified as fine, montmorillonitic, thermic, Entic Chromoxerert (Al-Turshan and Battikhi, 1993).

Plant materials: Shrubs were organized into two parallel rows, each extending 100 meters, with a 10-meter gap separating plants. Within these rows, seven distinct species were randomly distributed in plots, with six shrubs of each species in every row, ensuring a 2-meter spacing between individual shrubs. The species were: (i) three leguminous forage varieties (*Medicago arborea, Colutea istria,* and *Coronilla glauca*), (ii) three *Atriplex* species (*A. canescens, A. nummularia, A. undulata*), and (iii) spineless cactus pear (*Opuntia ficus-indica*). This arrangement was replicated three times, with a 5-meter gap demarcating each replication. The resulting strips formed by rows of shrubs were intercropped with annual crops, specifically wheat (*Triticum aestivum*), vetch (*Vicia sativa)*, and barley (*Hordeum vulgare*).

Plant measurements: To assess shrub growth characteristics, stem diameter and plant height were monitored. To evaluate biomass production, shrubs were carefully clipped at a height of 25 cm above the ground during their peak growth phase. A suitability index for each shrub species was computed, assigning scores ranging from 1 to 5 using a weighted factor model. This facilitated effective decision-making by prioritizing criteria based on five factors:

I. Forage production: Species were ranked on a scale from 1 (minimum biomass) to 5 (maximum biomass).

II. Forage quality: Determined using the palatability index, a well-recognized measure based on both local herders' indigenous knowledge and scientific references. The palatability index ranged from 0 to 5, indicating different levels of palatability: (0) complete avoidance, (1) occasional or poor palatability, (2) moderate preference and medium palatability, (3) good palatability, (4) very good palatability, and (5) complete preference and high palatability

(Le Houérou, 1962; 1965; Le Houérou and Ionesco, 1973).

III. Seasonal suitability for direct browsing: Categorized into three groups: (0) not suitable for grazing despite availability, (1) available only during peak feed availability, and (5) available during feed shortages periods.

IV. Ability for direct browsing: Ranging from 0 (not suitable for direct grazing) to 5 (available during feed shortages periods).

V. Impact on soil fertility: Scores ranging from 1 (erosion reduction) to 5 (nitrogen fixation) were assigned to assess its effect on soil fertility.

To ensure a balanced assessment, a weighted approach was adopted with the following percentage allocations: forage production (20%), forage quality (20%), season for direct browsing (30%), ability for direct browsing (25%), and impact on soil fertility (5%).

Data analysis: The trial was organized using a randomized complete block design. An analysis of variance (ANOVA) was performed using PROC GLM (SAS Institute, Cary, NC). To compare the yield means least squares means were used. In cases where significant differences were identified, Fisher's least significant differences were calculated at 0.05 probability level.

Results and Discussion

Shrubs height and biomass production: Shrub heights displayed significant variation among species (P <0.05). *Atriplex nummularia*, *Colutea istria* and *Atriplex canescens* stood out as notably taller (P<0.01) than *Coronilla glauca*, *Medicago arborea* and *Atriplex undulata* (Fig 1). Specifically, *Atriplex nummularia* reached the tallest height at 1.6 meters, closely followed by *Atriplex canescens* at 1.5 meters. In contrast, *Atriplex undulata* ranked as the shortest among all the *Atriplex* species at a height of 0.8 meters, while *Coronilla glauca* had the lowest height among all species included in this study, standing at just 0.6 meters. *Atriplex nummularia* and *Atriplex canescens* demonstrated significantly higher biomass production (kg DM/plant) compared to *Atriplex undulata* (Fig 2). Among the leguminous trees, *Colutea istria* exhibited the lowest biomass production at 0.5 kg DM/plant. However, no significant differences were observed among *Coronilla glauca, Medicago arborea* and *Opuntia ficus-indica*, all of which recorded a biomass of 0.7 kg DM/plant.

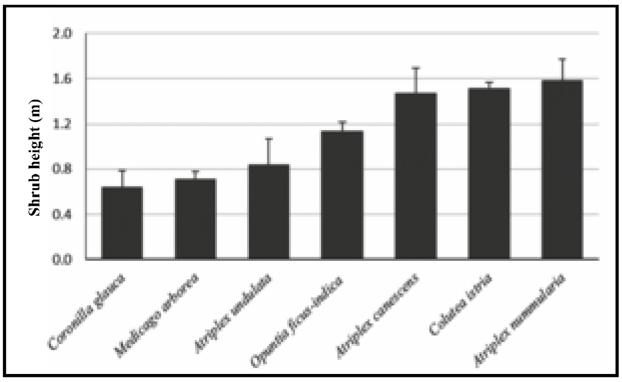

Fig 1. Shrub height variation among seven shrub species in an alley cropping system (error bars depict standard errors with a sample size of six for each species)

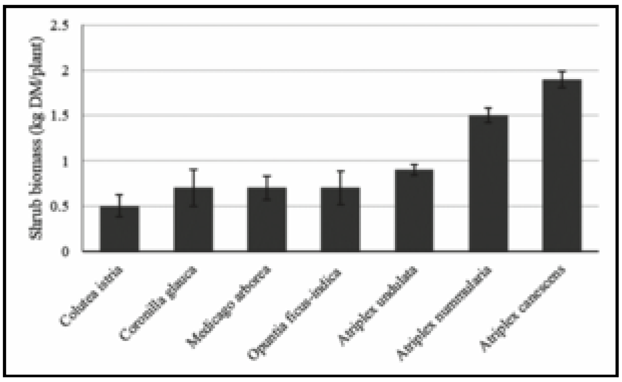

Fig 2. Shrub biomass variation among seven shrub species in an alley cropping system (error bars depict standard errors with a sample size of six for each species)

Selecting appropriate shrub species for semi-arid conditions involves a multifaceted decision-making process, taking into account factors like local climate, soil characteristics, water availability, and intended use, whether it will be for fodder, timber, or soil enhancement. Within this context, the substantial variation observed in shrub heights and biomass among different species becomes of paramount significance, especially when considering their integration into alley cropping systems. This variation could be ascribed, in part to differences in anatomical characteristics including variations in the thickness of the lower and upper epidermis, palisade and spongy mesophyll layers, dimensions of xylem vessels, and the root vascular bundle (Dong and Zhang, 2001). Additionally, physiological factors, such as leaf area index, leaf water relations, carbohydrate reserves, water use efficiency and leaf gas exchange might further contribute to this diversity (Erdmann *et al.,* 1993; Dong and Zhang, 2001; Stur *et al.,* 1994).

Of particular note was the significant divergence in shrub heights among species, which has direct implications for their suitability within alley cropping systems. Taller shrubs including *Atriplex nummularia, Colutea istria,* and *Atriplex canescens*, have the potential to provide effective alley configurations for purposes such as providing shade and windbreaks. These findings also underscored the superior biomass production of *Atriplex nummularia* and *Atriplex canescens* in comparison to *Atriplex undulata*, emphasizing their value as favorable shrub species in the context of alley cropping systems.

Conversely, among the leguminous trees, *Colutea istria* displayed the lowest biomass production, signaling its limited suitability for this context, a result consistent with Larbi *et al.* (2011). Despite *Opuntia ficus-indica* greater fresh weight, there were no statistically significant differences in biomass production among *Coronilla glauca, Medicago arborea,* and *Opuntia ficus-indica*, all of which exhibited similar biomass levels at 0.7. This could be attributed to *Opuntia ficus-indica* lower dry matter content (de Lemos *et al.,* 2021; Hassan *et al.,* 2020), suggesting equivalent performance among these species under the particular conditions of this study.

Weighted factor model: The highest score for forage production was achieved by *Atriplex canescens*, while the lowest was *C. istria*. In terms of forage quality, the leguminous shrubs outperformed the *Atriplex* and *Opuntia ficus-indica* species. *Medicago arborea* ranked first in this regard, followed by *C. istria* with *Coronilla glauca* ranking the lowest among leguminous species. *Atriplex* and *Opuntia ficus-indica* exhibited similar forage quality (Table 1; Fig 3). *Opuntia ficus-indica* was considered unsuitable for direct grazing due to its nature as a cut-and-carry crop, even though it remained green and available throughout the year. Apart from *Opuntia ficus-indica*, only *C. istria* received a lower score in terms of suitability for direct grazing with a value of 1, while other species scored 1.25. *Atriplex* species appeared to align best with the timing of high nutritional value forage among the shrubs, addressing seasonal feeding gaps effectively (Ghassali *et al.,* 2011). In contrast, leguminous trees received lower scores, indicating a conflict between their peak growth periods and the feasibility and necessity of grazing during those times.

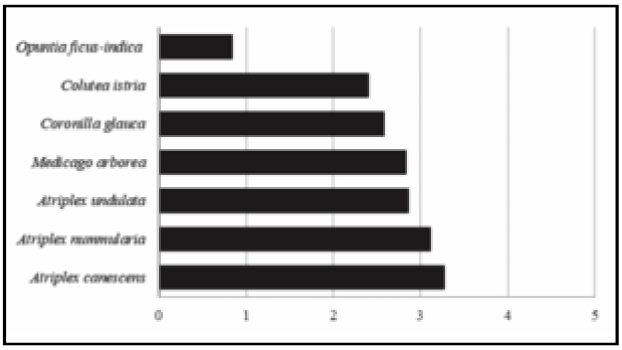

Fig 3. Shrub suitability index variation among seven shrub species in an alley cropping system

In alley cropping systems, the scope of agricultural functions extends well beyond the composition of trees and crops. Both tree and crop components contribute to valuable outputs including fodder and biomass, while the trees themselves provide benefits to soil health and other ecosystem services (Chaturvedi *et al*., 2016; McAdam *et al.,* 2009; Tsonkova *et al.,* 2014). In our study, the suitability of *Atriplex canescens* and *Atriplex nummularia* were

Table 1. Weighted factor of seven shrub species in an alley cropping system*

Shrub species	Forage production	Score (x 20%)	Forage quality	Score (x 20%)	Season for direct browsing	Score (x 30%)	Ability for direct browsing	Score (x 25%)	Impact on soil fertility	Score (x 5%)
A. canescens	5	1	3	0.6	5	1.5	5	1.25	1	0.05
A. mummularia	4	0.8	3	0.6	5	1.5	5	1.25	1	0.05
A. undulata	3	0.6	3	0.6	5	1.5	5	1.25	1	0.05
C. glauca	2	0.4	3.5	0.7	1	0.3	5	1.25	5	0.25
C. istria	1	0.2	4	0.8	1	0.3	4	1	5	0.25
M. arborea	2	0.4	5	1	1	0.3	5	1.25	5	0.25
O. ficus-indica	2	0.4	3	0.6	0	0	0	0	1	0.05

*Weight factors: Forage production (20%); Forage quality (20%); Season for direct browsing (30%); Ability for direct browsing (25%); and Impact on soil fertility (5%)

evaluated, both of which exhibited exceptional attributes in terms of forage production, availability and suitability for grazing. Notably, *Atriplex* species had the highest score aligning with the observed feed gap in Mediterranean conditions, typically from June to December. This period coincided with the seasonal growth patterns of *Atriplex* species, making them ideal choices for bridging seasonal forage shortages (Alotibi *et al.,* 2023; Neves *et al.,* 2007).

Conversely, despite their commendable attributes of high-quality and palatable forage, leguminous shrubs exhibited lower suitability. This could be attributed to their growth peak and superior forage quality during the spring, which coincided with the prime growth period of crops. Consequently, when animals graze on crop residues, the leaves of these shrubs tend to shed (Le Houérou, 2001). Additionally, the importance of *Opuntia ficus-indica* as a feed resource in dry regions could not be overstated. However, its nature as a cut-and-carry crop renders it unsuitable for integration into alley cropping systems. *Opuntia ficus-indica* is a multipurpose species widely cultivated in arid and semi-arid regions across the globe and holds increasing significance as a fodder crop, especially during drought periods and when other forage options are scarce. Nevertheless, our assessment yielded a low suitability index (0.8) for *Opuntia ficus-indica*, primarily due to the fact that direct browsing of *Opuntia ficus-indica* is not recommended.

Conclusion

Alley cropping stands out as a transformative agricultural practice that harmonizes economic viability, environmental sustainability, and social resilience. By integrating tree cultivation with traditional farming, it effectively addresses a myriad of challenges, from bolstering crop yields and enhancing soil health to mitigating climate-related risks and bolstering the prosperity of local communities. Its multifaceted benefits span various dimensions of sustainability, firmly establishing alley cropping as a dynamic strategy for fostering resilience and interconnectedness within our agricultural landscape. When implementing alley cropping systems, a crucial consideration revolves around the choice of shrub species. This decision entails weighing the trade-off between shrubs that yield substantial forage biomass to sustain livestock and those that contribute to improved soil nutrient status, thereby enhancing the conditions for field crop cultivation. Under west Asian conditions, *Atriplex* species stand out, boasting notably high suitability indexes, rendering them excellent candidates for direct grazing especially by small ruminants. This species flourishes under harsh conditions and delivers remarkable productivity and sufficient crude protein content, all while playing a significant role in promoting effective soil conservation.

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