Research and development work conducted under the Feeds and Forages Flagship of the CGIAR Research Program on Livestock

On farm and off-farm feed utilization and improved management options: A Synthesis

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CGIAR is a global partnership that unites organizations engaged in research for a food-secure future. The CGIAR Research Program on Livestock provides research-based solutions to help smallholder farmers, pastoralists and agro-pastoralists transition to sustainable, resilient livelihoods and to productive enterprises that will help feed future generations. It aims to increase the productivity and profitability of livestock agri-food systems in sustainable ways, making meat, milk and eggs more available and affordable across the developing world. The Program brings together five core partners: the International Livestock Research Institute (ILRI) with a mandate on livestock; the International Center for Tropical Agriculture (CIAT), which works on forages; the International Center for Research in the Dry Areas (ICARDA), which works on small ruminants and dryland systems; the Swedish University of Agricultural Sciences (SLU) with expertise particularly in animal health and genetics and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) which connects research into development and innovation and scaling processes.

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**Cover photo:** Women harvesting green fodder from dual-purpose wheat in Uttarakhand India. Photo ILRI/Sapna Jarial

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INTRODUCTION

The CGIAR Research Program on Livestock (Livestock CRP) provides research-based solutions to help smallholder farmers, pastoralists and agro-pastoralists transition to sustainable, resilient livelihoods and productive businesses that help feed future generations. It aims to increase the productivity and profitability of agri-food systems for livestock in a sustainable manner, and to make meat, milk and eggs more available and affordable in developing countries. To do this, five interacting areas are addressed through flagships that focus on the genetic potential of the animals kept, their nutrition, their health, their interaction with the environment, and the livelihoods opportunities livestock offer through better management, agri-business models and policies.

The flagship on Livestock Feeds and Forages aims to improve livestock nutrition by identifying, testing and delivering superior feed and forage strategies and options under four product lines: (1) Diagnostic, analytical and decision-making tools (2) New cultivars/varieties with increased feed quantity and quality (3) Feed preservation, processing and supplementation technologies and improved management options for rangelands and cultivated forages 4) Feed value chains and generation of small and medium-sized enterprises to provide affordable off-farm produced feed.

In mixed crop–livestock systems, which have the potential to intensify, the most important contributors to feed resources are forages, crop residues and rangelands. In pastoral and agro-pastoral systems, rangeland grazing is often the only source of feed. This report documents research and development undertaken under the third product line. The work builds on research carried out over several decades, by the International Livestock Research Institute (ILRI), the International Centre for Agricultural Research in Dry Areas (ICARDA), and the International Centre for Tropical Agriculture (CIAT) in collaboration with national researchers and extension services, as well as farmers and the private sector.
ORGANIZATION OF THE DOCUMENT

The challenges identified in the proposal of the CGIAR Research Program (CRP) on Livestock, for enhancing livestock production and productivity, have been the shortage of quality feeds, inefficient utilization of feed resources, degradation of rangelands, and lack of knowledge and skills of stakeholders in the feed production and utilization value chains. To address these challenges, the research and development work, innovations developed and tested, results-dissemination and concerted efforts towards capacity building have been presented in the following three main sections.

1) Enlarging the feed quality resource base
2) Efficient use of feed resources
3) Rehabilitation of degraded rangelands

Each piece of major work conducted in the respective sections has been presented separately with an introduction, salient findings, conclusion and way forward. At the end of each section, the main messages and lessons learnt from the respective pieces of work are presented. The work on dissemination of the research findings and capacity development, being an overarching subject, has been integrated into each of the three sections.

The reader would find some degree of overlap among these sections, for example some pieces of research conducted with the aim to enlarge feed resource base also included studies to increase feed-use efficiency. On the other hand, some work listed in the second section on the efficient use of feed resources also touched upon enhancing feed quality by converting the existing feeds to the novel ones. Likewise, activities on rehabilitation of degraded rangelands also addressed aspects such as increase in feed quality and feed-use efficiency. Also the use of cactus as a feed, mentioned in the first section, can also be used for rehabilitation of degraded lands, which is covered in third section. These overlaps are inherited in any livestock feed and feeding-related work that addresses challenges in a holistic manner, and therefore cannot be dispensed with. Nevertheless, the categorization of the work in the above-mentioned three sections will aid in reading and comprehension of a large body of work conducted under the multi-year CRP on Livestock.
ENLARGING THE FEED QUALITY RESOURCE BASE

Livestock provides food and income for almost 1.3 billion people across the world. Livestock production accounts for 40% of agricultural gross domestic product (GDP). Globally, livestock provides 34% of protein intake and 18% of dietary energy. Around 600 million of the world’s poorest households keep livestock as an essential source of income. Despite its importance, the development of the sector has been poor, mainly due to shortage of quality feed.

Grazing has long been a principal source of feed in much of south Asia and in sub-Saharan Africa. Due to population pressure, land degradation and conversion from grazing to arable land, grazing areas have contracted and resulted in feed shortages. The conversion of grazing land is likely to be aggravated by climate change. The increasing demand for animal-sourced food is another factor in putting pressure on feed from all sources. Despite the importance of livestock towards the global economy and livelihood of the farmers, low livestock productivity remains a major barrier to the development of the livestock sector. Shortage of quality feed has emerged as the major constraint for livestock production in many developing countries.

There is an urgent need to enlarge the types and quantity of feeds and to enhance their quality. This report begins with the synthesis of research and development work conducted through the CRP on food-feed crops with the objective of increasing both the availability and quality of feeds for the livestock sector and of food grains for human consumption. The focus of research has been on cereal and pulse crops. Thereafter, enhancing availability and quality of cultivated forages forms the subject of this section. The final two sections deal with two unconventional feed resources—cactus and cassava peel mash.

1.1 MULTI-DIMENSIONAL IMPROVEMENT OF FOOD-FEED CROPS

The crop residues (CRs), such as straws, stovers and haulms, provide 50–70% of the feed resources in smallholder systems, and cereal CRs have emerged as the main components of the livestock diet. The CRs
are generally poor in their nutritive value with a low crude protein content (ca 4%) and digestible organic matter (< 50%). Several attempts have been made to improve feeding value of CRs by using chemical, physical and biological treatments. However, little adoption has taken place despite substantial investments and efforts of international and national development and research organizations.

The lack of adoption of these treatments applied on the harvested CRs, gave way to a new model of improving their feeding value of CRs that focused on selection and plant breeding. In the mid-1990s, ILRI and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) started a joint programme on improvement of grain and CR traits, focusing on sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum* (L.) R. Br.) in the semi-arid tropics of India. *Ex ante* estimates of potential productivity gains from genetic improvement of the digestibility of multidimensional food and fodder crops showed high rates of economic return in the form of increased meat, milk and draught power. Similar work started in West Africa in the 1990s among the International Institute of Tropical Agriculture (IITA), ICRISAT and ILRI, targeting cowpea. Later ICARDA further extended this work to other food-feed crops such as barley, chickpea, field bean, faba bean and lentil. These research programs addressed several issues that explored the feasibility of increasing nutritive value of the CRs through genetic improvement (Blümmel et al. 2020). These were: the extent of cultivar dependent variation in CR fodder quality; exploitation of these variations without detriment to grain yield; quality improvements in CRs from plant selection and breeding; and assessment of such improvement on crop and animal productivity. A synthesis of main studies conducted under the framework of the project is presented below.

1.1.1 Leveraging traditional crops for food and feed: A case of hulless barley (*Hordeum vulgare* L.) landraces in Ethiopia

*Introduction*

Barley (*Hordeum vulgare* L.) has high economic and social importance as human food, malt for brewing and animal feed. In the mixed crop-livestock systems of Ethiopia, the potential contribution of barley straw to the feed supply of livestock is significant. Studies to simultaneously boost grain yield and straw nutritive value traits of cereal and grain legume crops are ongoing at ICARDA. Several studies have reported on the possibility of improving grain yield alongside straw traits of lentil, chickpea, maize and pearl millet. A focus on dual purpose hulless barley for high grain yield, high straw yield and high nutritive value would be particularly relevant for regions in Asia and Sub-Saharan Africa where straw feeding to livestock is commonly practiced. Landraces are still the backbone of agricultural systems in many developing countries because they are characterized by high genetic heterogeneity and good adaptation to local environmental conditions.

This study (Wamatu et al. 2019) explored food-feed traits in genotypes of 25 indigenous Ethiopian landraces, 13 landraces introduced into Ethiopia and 5 local checks of hulless barley (*Hordeum vulgare*). The genotypes were evaluated for straw fodder quality traits and the traits were related to grain yield and straw yield.
Salient findings

High genotypic variability in grain yield (5.1 tonnes per hectare (t/ha)), straw yield (7.03 t/ha) and straw content of crude protein (CP: 29.1 grams per kilo (g/kg)), neutral detergent fibre (NDF: 77 g/kg), acid detergent fibre (ADF: 41 g/kg), acid detergent lignin (ADL: 22.7 g/kg) and invitro organic matter digestibility (IVOMD: 72 g/kg) existed in Ethiopian landraces. The cluster analysis determined six genotypes (i.e. 243231, 241790, 219177, 243235, 241787, 241789) among Ethiopian landraces that showed food-feed traits with an average of 3.44 t/ha of grain, 5.64 t/ha of straw and 55.9 g/kg of CP. The correlation between grain yield with straw yield and nutritive value parameters was insignificant. Principle component analysis determined that CP and NDF or IVOMD can express the nutritive value of hulless barley straw.

Conclusion and way forward

Wide genetic variation in grain yield and straw traits in hulless barley indicates a high possibility to develop genotypes of hulless barley that combines superior grain yield for use as human food and straw traits for livestock feed. These varieties would be particularly beneficial for mixed crop-livestock systems that are predominant in developing countries. Ethiopian landraces could be a potential genetic pool for any effort to improve both grain yield and straw traits. However, variability in straw nutritive value should be confirmed for use by livestock. Further studies could include: 1) botanical structure and physical traits of straw; 2) effect of the environment on performance of hulless barely genotypes in terms of food and feed traits; and 3) more studies to identify inheritance of straw traits. These studies will assist crop breeders to design appropriate approaches to develop dual purpose genotypes of hulless barley.

1.1.2 Variations in food-fodder traits of bread wheat cultivars in Ethiopian highlands

Introduction

Mixed crop livestock farming is the dominant production system in the highlands of Ethiopia. In the highlands, grazing lands have been declining and farmers increasingly depend on crop residues as a source of fodder. Wheat is the most widely grown cereal in Ethiopia after tef (Eragrostis tef) and maize. Wheat is cultivated annually on more than 1.6×10^6 ha of land and produces an estimated 6.9×10^7 tons of straw dry matter. Most of the wheat straw produced is used on farm as fodder, but when sold in local fodder markets prices for straw range from 50-60% higher than that of the grain. As a result, the quantity of straw produced is important to smallholders, and this often influences farmers’ choice of variety.

In addition to increasing the quantity, improving the fodder quality of the straw is essential for smallholders to get optimal livestock output. Although several bread wheat cultivars have been developed for, and released in, the Ethiopian highlands, varietal differences in their food-fodder traits have largely been ignored.

A study (Bezabih et al. 2018) was conducted to examine the presence and extent of genotypic variation in food-fodder traits of 25 released bread wheat cultivars and to investigate for grain and straw yields and
straw fodder quality traits across two locations (Debre Zeit and Kulumsa). Five varieties were selected for further investigation at four locations representing a broader range of agroecologies. Straw fodder quality traits investigated were nitrogen (N), neutral detergent (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), in vitro organic matter digestibility (IVOMD) and metabolizable energy (ME).

**Salient findings**

Significant varietal differences (P < 0.001) existed across locations for grain yield (GY) and straw yield (SY), with GY ranging from 3.5 to 5.4 t/ha−1 (x̄=4.3 ± 0.24 t/ha−1) and SY ranging from 6.6 to 14.6 t/ha−1 (x̄=8.5 ± 0.20 t/ha−1). Varietal differences across locations were observed for NDF (74.6–78.0%; P < 0.01), ADF (48.5–52.3%, P < 0.001) and ADL (5.9–6.7%, P < 0.0001).

The location effect was significant (P < 0.0001) for GY and SY and all straw fodder quality traits, with significant variety by location interaction for GY. The GY and SY in Kulumsa were 2.5 and 1.7-fold higher than the GY and SY in Debre Zeit, respectively. Straw quality traits were superior (P < 0.05) in Debre Zeit compared to Kulumsa, but differences in quality were proportionally smaller than the differences in the yields. Within Debre Zeit, significant varietal differences were found for GY (P < 0.0001) and ADL (P < 0.01), and a trend was observed for SY (P=0.06). Within Kulumsa, significant varietal differences were found for GY (P < 0.0001), SY (P < 0.0001) and cell wall constituents (P < 0.05). A trend was observed for N content (P=0.07). There was a weak positive relationship between GY and SY (r=0.35, P=0.08) across the locations.

Grain yield was inversely related to N content of the straw (r = −0.45, P=0.02), but the relationship with the other fodder quality traits was not significant. No significant relationship was observed between SY and fodder quality traits.

Further studies on the five varieties differed significantly (P < 0.01) both in yield and fodder quality traits, except for ME (P=0.59). There was also significant (P < 0.01) variety by location interaction for N, and cell
wall constituents, in addition to GY. Overall, GY and SY differences among bread wheat varieties were more substantial than differences in straw fodder traits and a fair amount of elasticity exists between yields and straw quality traits that can be exploited.

Conclusion and way forward

The presence of cultivar-dependent variations in fodder quality traits of bread wheat varieties developed can be exploited to optimize food-feed traits of cultivars used in the mixed crop-livestock system. In general, compared to the first trial in which 25 varieties were tested across two sites, higher variability in fodder quality traits was observed in the second trial in which five varieties were tested across four sites, suggesting the importance of the role of environment in fodder trait expression.

Although the variation in fodder quality traits of wheat cultivars considered in the current study remained limited, considering the scale of wheat cultivation in the country which is the second largest in sub-Saharan Africa, a real potential exists to considerably improve livestock production even with a slight improvement in the fodder quality of the straw, due to variety selection. As an example, a one-percent unit increase in digestibility of sorghum and pearl millet stover result in increases in animal performance (milk, meat and draft power outputs) in the range of 6–8% (Kristjianson et al. 1999). The variability in IVOMD among the currently investigated wheat varieties ranged between one and two percent units. Theoretically, this means that by exploiting the existing varietal variations, it would be possible to improve the digestibility of the straw by at least one percent, which could be translated to approximately a 6% increase in animal performance. When this improvement in animal performance is combined with the number of animals (in thousands) that would be affected by the fodder quality improvement, the economic benefits become significant.

1.1.3 Selecting for food-feed traits in early and late maturing lentil genotypes (Lens culinaris)

Introduction

Lentil (Lens culinaris) is an annual cool-season legume primarily used for human consumption and the straw used as livestock feed. 81.5% of the total production of lentil in Africa is grown in Ethiopia. ICARDA has a world mandate for lentil improvement and is working with national programs across several countries to enhance production and productivity, increase incomes of farmers and provide lentil to consumers for food and nutritional security. Understanding of genotype by environment interactions, local constraints to production and consumer requirements for seed as food and straw as feed, has been a guide to the national and international breeding programs to develop new genetic materials for various agroecologies in west Asia, North and east Africa regions. In the predominant mixed crop-livestock systems of Ethiopian highlands, lentil straw is among fibrous crop residues from cereals and legumes that constitute large proportions of livestock feeds, particularly during dry seasons. Lentil straw has been reported to have better degradation in rumen and higher concentrations of crude protein and digestible energy than cereal straws routinely used as fodder. This offers an opportunity for livestock nutritionists
and lentil breeders to collaboratively explore the feasibility of genetic enhancement of not only grain traits but also straw yield and its nutritive value.

To explore genetic and environmental variability of food-feed traits in lentil genotypes, straws of 78 elite genotypes and four checks of early and late maturing lentil types were evaluated (Wamatu et al. 2017) for their nutritive value and potential trade-offs of the nutritive parameters with straw and grain yields. The effects of genotypic and environmental sources on variation in the nutritive value were also determined.

**Salient findings**

Results from eight trials carried out across three different sites in Ethiopia showed highly significant genotypic variation (P<0.05) in grain yield, straw yields and straw nutritive traits. This confirmed the existence of exploitable genetic variation in these traits. Similarly, the relationship between grain yield and straw yield was positive. The correlation between grain yield and nutritive parameters of straw was insignificant or negative, while that between maturity types and straw traits was either neutral or negative. Genotype by environment interactions were significant (P<0.05) for straw yield and nutritive traits indicating that variation in the traits is dependent of environment.

**Conclusion and way forward**

It is possible to develop genotypes with a combination of food-feed traits from early and late maturing lentil types to address the high demand for grain and livestock fodder in various agroecological zones in mixed crop-livestock farming systems using appropriate breeding approaches. It is vital to increase straw production as well as to enhance their nutritive value. Incorporation of straw nutritive traits in lentil breeding programs and varietal release criteria holds promise for enhanced livestock productivity in smallholder mixed farming systems.

1.1.4 Integrating straw yield and quality into multi-dimensional improvement of lentil (*Lens culinaris*)

**Introduction**

Lentil straw is an important source of fodder for livestock in Africa, south Asia and the Middle East. Lentil straw has been reported to have better degradation in the rumen as compared to cereal straws. However, improvement programmes of lentil do not pay attention to straw traits, neither are straw traits considered in release criteria of new varieties. This study (Alkhtib et al. 2017) aimed to determine whether straw traits can be integrated into multi-trait improvement of lentil.

**Salient findings**

Wide genotypic variation (P < 0.001) was found in grain yield, straw yield and nutritive value of straw. Urea treatment significantly (P < 0.01) improved the nutritive value of straw; however, the genotypic range (dry matter basis) was comparatively higher by 13.3 units, 56 units, 0.82 units, 106 units, 18.3 units
and 1.62 units in crude protein, in vitro organic matter digestibility, metabolizable energy, potential dry matter intake, potential crude protein intake and potential metabolizable energy intake respectively. Acid detergent fibre correlated very strongly (pooled r = 0.87) with other nutritive value parameters of straw, therefore, it can be used to screen lentil varieties for fodder quality. Furthermore, acid detergent fibre can accurately predict in vitro organic matter digestibility (R2 = 0.9) and metabolizable energy (R2 = 0.8). Straw yield weakly correlated (r = 0.39, P < 0.001) with grain yield while no relation (P > 0.05) was found between grain yield.

Among the barley cultivars studied, DZ-2012-LN-0195 significantly outyielded the local variety by 2 t DM/ha of grain, 5.77 t of straw DM/ha, 340 kg CP/ha of straw CP and 50 thousand MJ ME/ha of straw ME. The cultivar DZ-2012-LN-0191 has superior grain and straw traits. Furthermore, its straw meets 106%, 99% and 138% of DM, CP and ME maintenance requirement, respectively, of 30 kg live weight sheep.

**Conclusion and way forward**

The cultivar, DZ-2012-LN-0191 can be recommended as a dual-purpose lentil cultivar. The possibility exists to simultaneously improve grain yield and nutritive traits of lentil straw. Currently, improvement programmes of lentil do not pay attention to straw traits, neither are straw traits considered in release criteria of new varieties. Food–feed varieties of lentil would not only address the increasing demand for food and feed, particularly in mixed crop–livestock farming systems, but also contribute to soil health through providing additional biomass for soil mulching. Therefore, livestock nutritionists need to work with lentil breeders to select varieties which have superior food and feed traits.

1.1.5 Variation in the straw traits of morphological fractions of faba bean (*Vicia faba* L.) and implications for selecting for food-feed varieties

**Introduction**

Faba bean is not only an important source of food for households, but also an important source of nutrients for livestock. However, studies on the utilization of faba bean straw as livestock feed are limited. Studies on the varietal variation of faba beans have mainly focused on agronomic traits. These studies reported high genetic variation in plant height, number of pods per plant, seeds per pod, branches per plant and the duration of vegetation and maturity, which may lead to exploitable variation in straw yields and quality. The selection of faba bean varieties that combine superior food-feed traits could lead to enhanced food and feed security in mixed crop-livestock systems. Therefore, this study (Alkhtib et al. 2016) was undertaken to: 1) evaluate the nutritive value of straws from five varieties of faba bean grown under similar climatic conditions and 2) examine the relationship between grain yield and corresponding straw yield and quality.

**Salient findings**
A significant varietal variation in grain yield, straw yield and proportions of botanical fractions of straw existed. The improved varieties were superior to the local variety in grain yield, straw yield and potential utility index (PUI). The local variety had the highest proportion of stem and lowest proportion of leaf and pods. Significant varietal variations (P < 0.001) were detected in dry matter (DM), organic matter (OM), ash, IVOMD, ME but not in CP, neutral detergent fibre, acid detergent fibre and acid detergent lignin of whole straw. The leaves had the highest IVOMD and CP content, while pods were highest in ME. Canonical correlation analysis showed significant (P < 0.001) correlations between the nutritive value of whole straw and nutritive value and proportions of its botanical fractions. Grain and straw yields were positively and significantly (P < 0.001) correlated. Weak correlations were detected between grain yield and straw quality traits. Ranking the varieties differed when grain yield, straw quality scores and PUI were considered. However, the weak correlation existed between grain yield and straw quality, including straw quality index or PUI to select food-feed varieties of faba bean is still necessary.

**Conclusion and way forward**

The study confirmed varietal variation in grain and straw yields and the nutritive value of faba bean straw in the faba bean varieties. Moreover, the results suggest that selecting varieties of faba bean with high grain and straw yields will not negatively affect most of the parameters for straw quality. Due to the close relationship between crop and livestock production, animal nutritionists should strengthen partnerships with plant breeders in efforts to ensure that the focus to improve grain yield for human consumption is not detrimental to the nutritive value of crop residues fed to livestock.

**1.1.6 Genetic variability in food and feed traits of early maturing desi chickpea (Cicer arietinum) for multi-dimensional improvement**

**Introduction**

Chickpea, considered a dual-purpose crop in developing countries, is an important source of protein, minerals and vitamins for humans. Growing chickpea improves soil fertility through atmospheric nitrogen fixation, increases land-use intensity and provides households with a source of income. Studies on chickpea have reported wide genetic variations in grain yield, number of secondary branches per plant, number of pods per plant, biomass yield and plant height which could be used as an exploitable genetic variation in straw quality and yield. Evaluation of genotypic variation in straw yield and quality parameters helps to identify parental genotypes with superior straw traits for developing nutritionally superior cultivars.

Urea treatment is one of the most effective ways to improve nutritive value of crop residues, and it enhances crop residue digestibility markedly. Ease of application and abundance of urea in local markets at a cheap price makes urea treatment widely adopted in developing countries. Therefore, urea treatment can be used as a baseline to ascertain whether genotypic variability in straw quality can be exploited to attain significant improvement in nutritive value. No studies evaluated the potential of exploitable varietal variation in feed traits of chickpea to replace urea treatment. Thus, the aim of this study (Alkhtib et al.
was to determine whether genetic improvement of straw traits could provide an alternative replacement option to urea treatment.

**Salient findings**

Effect of variety, location and their interaction on grain yield, straw yield and straw nutritive value was significant (P<0.05). Urea treatment significantly (P<0.001) improved straw content of CP and metabolizable energy (ME) by 49% and 4%, respectively. The average exploitable genotypic range was higher than the effect of urea treatment by 8.3 units for CP and 0.35 units for ME. Correlation between grain yield and straw traits was weak in all locations.

**Conclusion and way forward**

Currently, varietal improvement programs of chickpea do not pay attention to straw traits, neither are straw traits considered in the release criteria of new varieties despite fodder shortages. Results of the current study show the possibility to simultaneously improve food and feed traits of chickpea by applying appropriate breeding programs. Therefore, livestock nutritionists need to work closely with chickpea breeders to select varieties that have superior food and feed traits. Straws in this study were evaluated for nutritive value using in vitro methods; however, their feeding value must be confirmed by in vivo results. Genetic improvement of the nutritive value of chickpea straw would decrease need for urea for straw treatment. That amount of urea would be used as a fertilizer by farmers to increase grain yield.

**1.1.7 Nutritive value of field pea (*Pisum sativum* L.) straw as influenced by variety, season, botanical fractions and urea pre-treatment**

**Introduction**

Field pea (*Pisum sativum* L.) is a cool-season crop and one of the major pulses grown in mixed crop-livestock production systems in tropical highlands, the Mediterranean, western and central Asia. ICARDA holds traditional landraces, improved germplasm and a unique set of wild crop relatives of field pea from all these regions and works with partners in respective countries to develop field pea varieties with improved productivity and quality. This study (Wamatu et al. 2017) aimed to: 1) assess the influence of variety and season on the nutritive value of straw; 2) test the ability of predicting the feeding value of field pea straw using the nutritive quality of leaves and stems; and 3) compare the enhancement of field pea straw quality using urea pre-treatment with varietal variation.

**Salient findings**

Variety had a significant (P < 0.05) effect on CP and ADL of the straw. The differences between the leaf and stem were significant (P < 0.001) for all chemical composition parameters. The season affected the nutritive value of the leaf but not of the stem. The nutritive value of the whole straw was strongly correlated with the nutritive value of the leaf (r = 0.87) and stem (r = 0.86). The range in CP content among
varieties was 56 g/kg DM, while urea increased CP content by only 22 g/kg DM. The range of ME among varieties was 0.7 MJ/kg DM, while urea increased ME by 0.39 MJ/kg.

**Conclusion and way forward**

The wide range in CP and IVOMD in field pea straws offers a good opportunity for selection and breeding for improved straw quality of field pea varieties. The varietal selection has the advantage of hybrid vigour (heterosis), urea treatment, the highly recommended method for upgrading crop residues of high fibre content and low-nitrogen content, requires technical, economic and labour input by farmers. Guidelines for mixing urea solution, method of sealing for incubation, time of incubation, cost and availability of inputs and the availability and skill requirements of farmers remain a challenge to the utilization of urea treatment across several smallholder farmers in developing countries, particularly in Sub-Saharan Africa. Therefore, varietal selection can be an alternative option for smallholder farmers to obtain crop residues of enhanced quality for their livestock. This would go a long way into improving smallholder agriculture in integrated crop-livestock systems by underpinning adoption of improved field pea varieties into the cereal monocultures and by improving livestock nutrition because of improved straw quality. Varietal improvements would also reduce the need for pre-treatments of straws. This would minimize the dependence that smallholder farmers tend to have on extension agents who usually facilitate the use of pre-treatments.

**1.1.8 Effect of barley variety on feed intake, digestibility, body weight gain and carcass characteristics in fattening lambs**

**Introduction**

Barley (*Hordeum vulgare* L.) is a multiple-purpose crop with high economic and social importance. It is grown to produce grain for human and livestock consumption and malt for brewing. The breeding and selection of barley has been focusing on the optimization of grain production, without due consideration of the yield and quality of straw as livestock feed. Newly improved varieties and cultivation methods have led to a decrease in straw yields. Improved varieties have been rejected because of poor straw traits in crops including barley and finger millet.

A study (Keno et al. 2021) was conducted to evaluate the effect of straw from different barley varieties on the feed intake, digestibility, body weight gain and carcass characteristics of Horro lambs. The four treatments tested were: 1) a local barley straw (as control), 2) HB1963 (high grain and straw yields), 3) Traveller (high straw yielder), and 4) IBON174/03 (high grain yielder). A concentrate (50:50 wheat bran and noug seed cake) was offered constantly (300 DM g), whereas the straw was offered *ad libitum*. The digestibility trial and the growth performance trials lasted for 22 and 90 days respectively.
Salient findings

The CP concentration of the barley varieties ranged from 4.3% in the local variety to 5.5% in IBON174/03. The IBON174/03 variety had a higher (p < 0.05) intake of organic matter and crude protein, a higher dry matter and organic matter digestibility than the control and 10-19% higher body weight growth when fed straw of barley variety IBON174/03 compared with other barley varieties. The feed-to-gain ratio was similar among treatments. The slaughter and empty body weights of lambs in the IBON174/03 group were higher than the control variety (p < 0.05). The best performance with IBON174/03 was a direct effect of the increased intake and digestibility.

Conclusion and way forward

The feeding value and growth performance of sheep can depend on the barley variety that provided the straw in their diet. In particular, the IBON174/03 barley variety was the most promising in terms of the feeding value of the straw, hence it could be recommended as a more suitable candidate in the study area. This study showed the importance of barley variety when straw is a substantial part of a ruminant’s diet, such as in tropical conditions. Supplementation with oil seeds cake or other nitrogenous feeds is a must to achieve the desired growth rate. The feeding value of barley straw can differ substantially between varieties and therefore must be considered in the choice of a barley variety and in the selection criteria for barley varieties, to enhance livestock productivity in addition to grain yield for human consumption.

1.1.9 Effects of feeding different varieties of faba bean (Vicia faba L.) straws with concentrate supplement on feed intake, digestibility, body weight gain and carcass characteristics of Arsi-Bale sheep
**Introduction**

Ethiopia is one of the largest faba bean producing countries in the world second to China. The country is considered as the secondary centre of diversity and one of the nine major agro-geographical production regions of faba bean. Farmers in the highlands of Ethiopia practices crop rotation, especially rotation of cereals and faba bean, to alleviate the mono cropping problems. The use of faba bean straws as animal feed becomes important because of the conversion of many former grazing areas into croplands needed for increased food production.

Crop residues vary greatly in chemical composition and digestibility depending on species and variety of the crops. Chemical composition of a feed is highly variable not only between straw types but also within each class of straw. A study (Wegi et al. 2018) was conducted to evaluate the varietal differences among faba bean straws and to assess the potentials of faba bean straws supplemented with concentrate fed at the rate 70% straws and 30% concentrate mixture on feed intake, digestibility, body weight gain and carcass characteristics of the Arsi-Bale sheep. Straws included in the study were from Mosisa (T1M), Walki (T2W), Degaga (T3D), Shallo (T4S) and local (T5L) varieties of faba bean.

**Salient findings**

Local varieties had lower (p<0.05) grain and straw yields compared to improved varieties, but the local varieties were higher in crude protein, metabolizable energy contents and in vitro organic matter digestibility. The apparent digestibility of dry matter and crude protein of sheep fed Walki and Mosisa straws were higher than (p<0.05) those fed straws from Shallo varieties. Sheep fed Walki straw had greater (p<0.05) dry matter intake, average daily gain and feed conversion efficiency than sheep fed local and Shallo straws. Slaughter body weight and empty body weight were higher (p<0.05) for sheep fed Mosisa and Walki straws as compared to those fed Shallo straws. Other carcass components were not affected (p>0.05) by feeding of straws of the faba bean varieties.

**Conclusion and way forward**

A significant varietal difference between faba bean straws both in quality and quantity existed. Similarly, significant variation was observed in feed intake, digestibility, body weight gain and feed conversion efficiency among sheep fed different straws of faba bean varieties with concentrate supplement. Based on these results, Walki and Mosisa varieties could be recommended as pulse crop rotation with cereals in the study area. Higher potential for providing better quality straw from these varieties can help livestock production and productivity in addition to grain yield for human consumption. The study also highlighted the need to supplement faba bean straw with a concentrate (e.g. a mix of bran, oilseed cake, grains vitamins and minerals) to achieve high livestock productivity.

**1.1.10 IMPACT AND LESSONS LEARNT**
The synthesis illustrates that straw quantity and quality can be enhanced without compromising the grain yields through plant breeding approaches for several crops such as sorghum, barley, pearl millet, chickpea, faba bean, field bean and lentil. The impact of, and lessons learnt from, this work on genetic improvement of crops, led and conducted by ILRI, ICARDA and other national and international organizations, can be divided in three broad categories: scientific, developmental, and capacity and partnership building.

**Scientific.** One of the major achievements of the research findings was the change in the crop-improvement paradigms that earlier focused on only grains improvement to the whole-plant optimization. It forced a reconsideration of the single-trait (i.e. grain) model in favour of the multi-trait and whole-plant (i.e. food and forage) model. While there are few public-sector decisions to include stover traits as cultivar release criteria (sorghum and pearl millet are recent examples), public and private crop-improvement programmes have reoriented their efforts towards whole-plant improvement. The crop-improvement paradigms changed to whole-plant optimization, as, for example, reflected in the CRP on Grain Legumes and Dryland Cereals.

Scientific finding that led to change of paradigm to the whole-plant improvement are: 1) there is significant variation in CR quality and 2) such variation does not compromise grain yield. In the process extensive research and development was made on the near-infrared spectroscopy (NIRS) and molecular tools – the former for accurate and rapid screening of feeding quality traits such as protein, starch, amino and fatty acids, and the latter to detect variations in fodder quality early in breeding material.

The study conducted by ILRI and its partners and others across the globe showed that the nutritional quality of CRs can be increased by targeted genetic enhancement using conventional or molecular crop-improvement approaches such as marker-assisted breeding, use of quantitative trait loci (QTLs) or genome-wide association studies (GWAS). The research led by ILRI used stay-green QTLs in sorghum, while GWAS was used to unravel favourable native genetic variations for traits of agronomic and economic importance across cereal crops. Other laboratories used QTL to map the genomic regions controlling stover quality and yield traits in pearl millet.

Genomic selection (GS) or marker-enabled predictions can predict untested phenotypes from whole-genome information. The project developed a GS model of fodder quality traits to predict superior lines from a collection of doubled-haploid lines from the maize work of the International Maize and Wheat Improvement Centre (CIMMYT) in Asia.

Small differences in CR fodder quality resulted in substantial differences in livestock productivity because of the additive effects of higher diet quality and higher feed intake. This was evident from several project studies, for example:

1) 5 kg higher daily milk on feeding blocks containing premium sorghum stovers (52% IVOMD) than those containing low-quality stover (47% IVOMD)
2) two-fold difference in weight gains in sheep (from 65 to 137 g/day) depending on haulm fodder quality difference among groundnut cultivars
3) Similar proportional genotypic variations obtained for faba bean haulms
4) 10-19% higher body weight growth when fed straw of barley variety IBON174/03 compared with other barley varieties.

Developmental. Market studies in India and west Africa have identified significant differences in CR prices attributable to CR feeding quality. This information and the findings from the adoption studies that the materials with higher straw digestibility improve livestock productivity are valuable to crop extension programmes. Plant breeding and selection have led to the availability of crop cultivars with higher-quality CRs in sorghum, pearl millet, groundnut, rice and maize in India; in cowpea in West Africa; barley and legume crops in Ethiopia. Some examples are:

1) Identification of a multidimensional maize hybrid (NK 6240) by an ILRI-CIMMYT collaboration, which is now a very popular hybrid in India. ILRI, CIMMYT and Syngenta are now exploring branding for CR fodder quality traits.
2) Adoption of improved multidimensional cultivars based on seed production has been difficult and at times contradictory to estimate. Randomized adoption studies by household surveys showed generally less adoption than estimates based on seed production.
3) Adoption of hybrids was much faster because seed availability was less of a problem than with open-pollinated varieties. Thus, a new dual-purpose maize hybrid (MHM4070 or Lall-454) specially bred by CIMMYT and ILRI for high temperatures in India reached more than 23,000 ha within three years.
4) Concomitant increases of about 10% each of pod yield, haulm yield and haulm fodder quality in some new cultivars has provided sufficient incentives for their fast and large-scale adoption.
5) The straws of barley cultivar, IBON174/03 and of Walki and Mosisa varieties of faba beans have higher nutritional quality, the feeding of which increased livestock productivity.

Higher productivity and income were derived from sale of CRs and from increased livestock production.
Farmers under the Government of Karnataka project received improved NK6240 dual purpose maize seeds. Photo ILRI/Nithinkumar, D.M.

Fodder market studies in south Asia and west Africa have shown that: 1) market prices reflect fodder quality differences within and between crops; 2) customers are willing to pay price premiums for apparently small differences in fodder quality traits; 3) the price of CRs relative to grain has increased during recent decades; and 4) in some Indian markets, income from CR sales exceeded that from grain sales.

**Capacity building and partnership building.**

In the area of multidimension improvement of crops, ILRI has established scientific partnerships in the CGIAR system with ICRISAT, CIMMYT, IITA, ICARDA, national agricultural research and extension systems (NARES) in Ethiopia (Ethiopian Institute of Agricultural Research, EIAR) and India (National Research Centre for Sorghum, now the Indian Institute for Millet Research, IIMR) and the private sector (SeedCo, Syngenta and Advanta).

Affordable and comprehensive phenotyping for food–feed and fodder traits in all key cereal and legume crops is feasible now. The ILRI-crop-centre collaboration developed and validated NIRS equations for N, NDF, ADF, ADL, IVOMD and ME of CRs of sorghum, pearl millet, groundnut, pigeon pea, chickpea, cowpea, rice, wheat and maize. ILRI NIRS specialists have trained hundreds of laboratory technicians from public and private sectors in south Asia and east and west Africa on NIRS operations. NIRS hubs exist in India and
Ethiopia, and NIRS hubs are being established in Nigeria, Mali and Burkina Faso. These hubs are based on NIRS equations developed by ILRI and partners and on extensive training given by ILRI NIRS specialists.

1.1.11 OVERALL CONCLUSION, LESSONS LEARNT AND WAY FORWARD

Little adoption of chemical, physical and biological treatments applied on post-harvested CRs to improve their quality gave way to a new model of improving their feeding value by selection and plant breeding. It was successfully applied for several cereal and legume crops in Asia, west Africa and east Africa. One of the major scientific achievements of the research has been the change in the crop-improvement paradigms that earlier focused on only grain improvement to the whole-plant optimization. This change in approach is being currently adopted by many plant breeders working on improvement of cereal and legume crops.

The fodder quality of CRs can be increased by targeted genetic enhancement using conventional or molecular crop-improvement approaches such as marker-assisted breeding, use of QTLs or GWAS. A GS based model has been developed to predict fodder quality of untested phenotypes of CRs.

Plant breeding and selection have led to the availability of crop cultivars with higher-quality CRs in sorghum, pearl millet, groundnut, rice and maize in India; cowpea in west Africa; and barley, chickpea, faba bean, field bean, lentils in Ethiopia and east Africa. The increases in feeding quality of CRs without having any adverse effect of grain quality or yield. Small differences in CR fodder quality produced substantial differences in livestock productivity because of the additive effects of higher diet quality and higher feed intake. The differences in quality of CRs are reflected in their purchasing prices in the field – higher the quality, higher the price. Increase in livestock production and income of farmers have been realised by using CRs of higher feeding value. The genetic approaches have higher potential to increase quality of straws and stovers when compared to the urea treatment (considered to have wide potential applicability in developing countries) of such crop residues.

The traditional large-scale seed sector can bring hybrid crop cultivars to scale and collaborate in their ‘branding’ and seed labelling processes. Small- and medium-sized seed enterprises can move new cultivars from proof-of-concept stage to pilot stage by multiplying basic/foundation seeds of OPVs (open-pollinated varieties)/niche crops, often obtained from NARES. Once a threshold in supply of OPV seeds is passed, farmer-to-farmer seed exchange becomes significant. Small- and medium-sized feed enterprises can: 1) provide decentralized feed processing and value addition to improved CRs, 2) enhance income and employment opportunities to disadvantaged rural people, and 3) act as a ‘pull factor’ for the adoption of new cultivars. Large dairy enterprises using smallholder milk suppliers can serve as mediators and conveyors of new cultivars, feed intervention packages and customers for existing small- and medium-sized enterprises and as stimulators of new ones.

ILRI and ICARDA have enhanced the capacity of several researchers from a wide range of international and national institutions in multidimension improvement of crops, and in the use of NIRS to determine feeding quality traits in CRs as well as grains. NIRS hubs exist in India and Ethiopia, and such hubs are being
established in many other countries by ILRI. Both feed industry, academia and research organization will benefit from these hubs.

The holistic approach that focuses on whole crop improvement and not only on grain improvement should form a part of the master and PhD degree curricula. In addition, wider promotion of the results and impact of the work done by ILRI, ICARDA and other CGIAR institutions on multi-dimensional genetic improvement of feed-food crop under the CGIAR-UN framework, for example through an international conference (with the Food and Agriculture Organization of the United Nations (FAO) as the main partner) involving policy makers and science managers, would amplify the application of this approach. This could play a vital role in enhancing feed and food security in developing countries. A requisite for eliciting a large-scale impact of such a program is strong collaboration between animal scientists and plant breeders.
Livestock production is one of the main pillars of Ethiopia’s economy and the country possesses one of the highest livestock populations in the world. The livestock sector contributes about 46% to the agricultural GDP and provides employment opportunities to more than 68% of the population. Despite its importance, low livestock productivity mainly due to lack of quality feed, remains a major barrier to the development of the livestock sector in Ethiopia. Shortage of feed has emerged as the major constraint for livestock production in many developing countries including Ethiopia.

The major sources of livestock feed in Ethiopia are open grazing on pastureland, crop residue left over after harvest, and weeds from arable land. Open grazing from pastureland contributes the largest share. The use of crop residues is substantial, but their nutritive value is poor. The open pasture is often exhaustively grazed and therefore stored crop biomass, generally of poor quality, is consumed before the rainfall season starts. The productivity of livestock in Ethiopia is constrained by the seasonality of feed quality and quantity. Grazing lands are decreasing. Poor soil fertility and unreliable and seasonal rainfall limit the quality and quantity of pastures available from these areas.

Under these scenarios, improved cultivated forages could contribute to alleviation of feed shortages because of their higher biomass and nutrient outputs per unit area as compared to the rangeland pastures. Most cultivated forages have a good mix of protein, energy, vitamins and minerals, which makes the preparation of balanced diets easier for the livestock. Also, they can replace a substantial part of concentrates (which are generally expensive), leading to decrease in the cost of feeding and increase in profit to the farmers. Development of improved forage production systems can contribute to poverty reduction goals by enhancing livestock productivity, in addition to increasing social-ecological resilience through building risk buffering assets, both at the household and landscape levels.

ILRI and its partners have conducted several research and development studies on cultivation, use and impact of improved cultivated forages. Some of the research findings have been applied in the region
through the USAID-funded (US Agency for International Development) AFRICA RISING (Africa Research in Sustainable Intensification for Next Generation) project. A synthesis of these activities is presented here. Major studies conducted through the CRP have been presented as an individual study with its own introduction, salient finds, and conclusions and way forward. At the end a section, ‘Overall conclusion, lessons learnt and way forward’ draws important learnings from all the individual studies.

1.2.1 Livestock production challenges and improved forage production strategies in Ethiopia

Introduction

Ethiopia has a large livestock population, with an estimated 60.4 million cattle, 31.3 million sheep, 32.74 million goats, 11.32 million equines and 1.42 million camels. Despite the quantity and importance of these animals, their productivity is low due to several factors such as inefficient management, poor infrastructure, poor marketing and credit facilities, feed shortages both in quality and quantity and health constraints. To apply appropriate interventions, it is imperative to identify major production challenges, and to understand improved forage production strategies to address feed-related constraints. A semi-structured questionnaire was used to identify major livestock production constraints and improved forage production efforts in the Damot Gale district (Mengistu et al. 2021).

Salient findings

The major livestock production constraint was feed shortage, and a large proportion of farmers (75.6%) faced this problem. Other constraints included water shortage, disease occurrence due to poor veterinary services and poorly developed technical skills, seasonal inconsistencies of market demand for animal and
animal products and poor genetic potential of animals due to lack of progress in breed improvement programs.

Purchasing grass (31.4%) and concentrate (33.5%) and feeding enset (*Ensete ventricosum*) leaf (21.49%) were the most adopted coping mechanisms to alleviate feed shortages during the dry season. Desho grass (*Pennisetum pedicellatum*) (71.38%) and elephant grass (*Pennisetum purpureum*) (42.63%) were the common improved forages in the district. These were produced for use as feed, selling to other farmers and preventing erosion. Greatest constraints for improved forage production were seed/planting material shortage followed by land shortage and lack of awareness. Availability of high-protein feeds like legume forages is negligible.

**Conclusion and way forward**

The primary constraint for increasing livestock production is the lack of quality feed. Increased availability of good quality forage requires intensification and expanded availability of quality seed and planting material, use of good agronomical practices and capacity building. Increased cultivation of forage crops might result in land competition for food crop production, which can be decreased by using quality seed and planting material and use of agronomical practices that increase forage yield per unit area, and introduction of legume forages that can be integrated with other cropping systems. Strong extension services and efficient input delivery for farmers are vital to support profitable livestock production and resource utilization. The outputs of the study could guide research and development stakeholders to design production and resource utilization strategies to overcome existing constraints.

**1.2.2 On-farm performance evaluation of Brachiaria, Napier and Desho grass varieties in southern Ethiopia**

**Introduction**

Cultivated forages offer an alternative option to ease feed resource scarcity in the smallholder systems, as shortage of good quality livestock feed has become a major constraint for year-round feeding in Ethiopia. This is mainly because grazing lands, which have served as the main source of feed for decades, have shrunk in size over the years and the remaining pasture lands are threatened by overgrazing and land degradation. Cultivated forages can serve as a good source of supplement to locally available feeds, mainly crop residues. Such practices have been found to be economical for smallholder farmers who have limited access and capacity to purchase supplemental feeds. Improved grass forages have wider adaptation to climatic and soil conditions, which makes it easier to fit them to different farming contexts. Grasses also play an important role in the maintenance of natural ecosystems by reducing soil erosion and improving carbon sequestration when they are integrated with natural resource management practices.

An on-farm evaluation and demonstrations of grass forage varieties was conducted in southern Ethiopia through the BMZ funded project called grass2cash (Bezabih et al. 2019). The on-farm performance evaluation was conducted using Napier (*Pennisetum purpureum* var ILCA/ILRI 14984), Brachiaria (hybrid cultivar - Mulato II, and *B. decumbens* var Basilisk) and Desho (*Pennisetum glaucifolium* var Areka (DZF
590) grass varieties. The evaluation was implemented by involving more than three hundred farmers across three districts. In addition, an on-station controlled trial was conducted to compare the performance of two Brachiaria varieties (Mulato I and II) grown under different planting space and harvesting conditions.

**Salient findings**

Except *Brachiaria decumbens*, which failed to establish during the trial period, the other grass varieties established well. The biomass yield of the Napier grass (ILRI 14984) (18 tons DM/ha) was considerably higher than those of Mulato II Brachiaria (7.2 t DM/ha) and Desho grass (8.4 t DM/ha).

The CP contents of Napier grass and Desho grass were 8.6% and 9.1% respectively. Quality of Mulato II was superior, with high crude protein (19%) and a moderate level of fibre. The in vitro organic matter digestibility followed the same pattern as the CP. However, the nutrient yield (CP, digestible organic matter and ME) per hectare was still much higher for the Napier variety than the other grasses. These values for ME were: Napier grass 129 GJ ME/ha), followed by the Desho grass (66 GJ/ha) and Mulato II (57 GJ/ha); and for CP: Napier grass, 1.55 t/ha) followed by Mulato II (1.33 t/ha) and the Desho grass (0.76 t/ha).

In an on-station comparison, Mulato I variety performed better in terms of upright growth, tiller count and biomass yield than Mulato II variety. In the same trial, differences in planting space affected the biomass yield in the first season, but not in the subsequent season, suggesting that the tillering capacity of the two varieties can offset open spaces as the forage establishes. Harvesting the two varieties after 90 days of growth provided the maximum biomass and nutrient yield with minimal loss of fodder quality.

**Conclusion and way forward**

The grasses evaluated in this study were generally favourably accepted by farmers. While Napier grass remains the highest yielding grass in terms of dry matter and nutrient yield, the Brachiaria and Desho grass varieties provide alternative options with better fodder quality. In areas where land is limiting Napier remains a grass of choice to produce high biomass and nutrients.

The hybrid Brachiaria grasses have a high CP content (> 18%) and reasonably low fibre content, suggesting their potential to support optimal livestock productivity and to be used as a supplement to other local feed resources. Brachiaria Mulato II is a better option than Mulato I in terms of dry matter and nutrient yields for smallholder farmers. Also, farmers value the leafiness and softness of Mulato II compared to the other grasses. However, spider mite pests pose a challenge to scale both the hybrid Brachiaria grasses, and a close follow up and management should be put in place to overcome the pest problem. Harvesting the Brachiaria hybrids after 90 days of growth would provide higher biomass and nutrient yield with minimal loss of quality.
Effective integration of cultivated forages in the smallholder crop-livestock system requires demonstration and promotion of suitable and context specific forage genotypes as well as use of best agronomic practices. These grasses may be propagated after understanding farmers’ requirements and production objectives. The use of Napier and Desho grasses is largely as a basal diet and these would require supplementation of protein-rich concentrates for achieving high animal productivity, while Brachiaria grasses would be used as supplements to low quality crop residues and have potential to support high producing animals.

### 1.2.3 Determinants of survival and growth of tagasaste (*Chamaecytisus palmensis*) in the crop-livestock farming systems of the Ethiopian highlands

**Introduction**

Identification of different options to enhance crop and livestock productivity and diversify income sources are key priorities to improve livelihoods of smallholder farmers. Integration of tree species, such as tree lucerne (*Chamaecytisus palmensis* (Christ) Bisby and Nicholls), in crop-livestock farming systems is one potential option to support fodder availability, improve soil fertility and enhance crop-livestock productivity. The plant is well-adapted to highland areas (2000–3000 metres above sea level (masl)), grows fast and fixes nitrogen. It is unusual amongst N-fixers in being adapted to the upland environments of the Ethiopian highlands. Tree lucerne has a good potential for use as livestock fodder. Its leaves are highly palatable and have 20–30% crude protein and high digestibility of the order of 80%. The annual biomass yield is reported to reach up to 10 tonnes of dry matter per hectare. This tree, therefore, can play an important role in bridging seasonal feed shortages and can serve as a protein supplement to enhance the feeding value of local feed resources especially crop residues. However, the performance, expansion and contribution of these plant species have not reached full potential due to several reasons. Previous research on tree lucerne and other fodder tree species in the highlands of Ethiopia focused primarily on surveys of existing fodder tree species, screening and adaptability of provenances and species and few feeding trials. To date, there have been limited efforts to demonstrate to farmers the management and utilization of different plant parts for various potential products and services. Since no studies have empirically looked at how these factors influence on-farm survival and growth rates of fodder tree species.

On-farm research (Mekonnen et al. 2016) was conducted to: 1) compare survival and growth of tree lucerne across contrasting sites and growing niches, and 2) identify the key determinants of tree lucerne survival and growth on farms in the crop-livestock systems. The research was conducted in eight research kebeles (the smallest administrative unit in the country) of the four AFRICA RISING project sites.

**Salient findings**

The percentage survival on-farm was significantly higher for tree lucerne planted in backyards than those planted in outfields, and for middle-resource class households than for households within the resource rich and resource poor types. Browsing by animals also decreased the survivability of tree lucerne.
Household size, access to reliable water supply and management factors including fencing and watering the planted seedlings, mulching during dry periods, clean spot weeding and applying organic fertilizers, all significantly enhanced survival and growth of tree lucerne in the planting sites. Overall, tree lucerne survival and growth was mostly affected by management factors. These management factors were more critical and significant at the establishment phase of the plants to ensure survival of the plant than in the later growth phases of the plant. Equal access to resources by men and women farmers fostered equal survival and growth of tree lucerne on farms managed by men and women.

Tree lucerne in well-managed farm fields can grow to a reasonable size for harvest and use as animal feed within nine months after planting.

**Conclusion and way forward**

Availability of information on key determinants of survival and growth of tree lucerne (e.g. higher survival of tree lucerne on-farm in backyards and for middle-resource class households, and decreased survivability by browsing) and the lessons learnt (e.g. proper management of the plant at the establishment phase) would help to improve large-scale adoption and unlock the full potential of this multipurpose fodder tree in the mixed farming system. These will also be valuable inputs for future research and development initiatives on the integration of fodder tree species into crop-livestock systems. Follow up research on cutting frequencies and utilization with various local feed resources and feeding to targeted livestock species is necessary.

For farmers to successfully grow tree lucerne on their farms, researchers, extension officers and farmers should work jointly to identify leverage points for integrating tree lucerne in existing farming systems and capacitate local farmers on tree lucerne management. Targeting farmers that can plant, properly manage and utilize tree lucerne is essential to improve adoption in the Ethiopian highlands. Particularly, targeting and working intensively with medium-resourced farmers with a fair amount of land and livestock, who can readily apply essential pre-and post-planting management practices can result in early adoption of tree lucerne. Backstopping farmers through the formation of research groups is a useful approach to enhance innovation and cross learning. Adoption by farmers is likely to be easy if they can learn by seeing. A targeted approach could therefore create a learning centre in each action site, from which others could receive experience and adapt the required management practices.

1.2.4 Constraints of small-scale irrigated fodder production and nutrition assessment for livestock feed — a case study in Ethiopia

**Introduction**

The major sources of livestock feed in Ethiopia are open grazing on pastureland, crop residue left over after harvest and weeds from arable land. Open grazing from pastureland contributes the largest share. The open pasture is often exhaustively grazed and therefore stored crop biomass is consumed before the
rainfall season starts. It is a common phenomenon for feed shortage to occur during the dry season and pose a major challenge for overall feed quality and quantity.

Different species of forage grasses, legumes and trees are used as feeds for livestock in tropical and subtropical regions. In Ethiopia, Napier grass (*Pennisetum purpureum*), vetch (*Vicia villosa*), oats (*Avena sativa*), alfalfa (*Medicago sativa*) and Desho grass (*Pennisetum glaucifolium*) are some of the most widely used fodder crops for livestock feed due to their high yield and easy management. Besides cattle feed, these fodder crops are widely used for soil and water conservation, fuelwood supply and input to biogas production.

There are limited studies in Ethiopia that identify and review environmental factors that limit the ability to produce optimal feed and access the nutritional quality of different fodder crops. Therefore, a study (Worqlul et al. 2012) was conducted to evaluate the gaps and constraints of fodder and nutritional potential for livestock feed using small-scale irrigation (SSI). The study comprised of 30 randomly selected farmers from two different ecological zones in Ethiopia. Half of the farmers cultivated Napier grass (*Pennisetum purpureum*) in the Robit watershed in northern Ethiopia, and the other half cultivated mixed vetch (*Vicia villosa*) and oats (*Avena sativa*) in Lemo watershed in southern Ethiopia. The Soil and Water Assessment Tool (SWAT) and Agricultural Policy Environmental eXtender (APEX) were applied in an integrated manner to assess the impacts of SSI at the watershed and field-scale levels, respectively.

*Salient findings*
The watershed-scale analysis showed that there is a substantial amount of surface runoff and shallow groundwater recharge that could be used for dry season fodder production using irrigation. Field data calibrated APEX model suggested that Napier yield could be maximized with 550 mm of water in Robit watershed. While in the Lemo watershed, maximum vetch and oats yield may be achieved with 250 mm of water.

The nutritional analysis showed that Napier grass has a higher dry matter and ash (mineral) content than the oats and vetch. However, vetch has higher crude protein content (18%) compared to Napier (10%) and oats (6%). The major constraints for Napier and oats production were soil fertility, especially nitrogen and phosphorus and vetch production was limited by high temperature.

**Conclusion and way forward**

There is a substantial amount of water resources in both the watersheds to produce fodder production using small scale irrigation. The modelling results showed that the average optimal amount of water required to cultivate Napier and a mix of oats and vetches is around 550 and 250 mm, respectively. The application of irrigation beyond the optimal amount for the respective fodder crops increased surface runoff and percolation that cause nutrient losses. The poor soil fertility limited optimal fodder production in both watersheds. For example, phosphorous was one of the major yield-limiting factors for vetch production, although nitrogen was not a limiting factor as vetch is a legume crop.

Napier has a higher dry matter content compared to oats and vetch. Napier also has a higher mineral content, while vetch contains high crude protein and energy content. Overall, oat and vetch provide a superior nutrition performance as a livestock feed.
Besides providing high biomass, dry matter content, crude protein, and energy for livestock, fodder crops such as vetch provided other environmental services. For example, vetch crop can symbiotically fix atmospheric N through nitrogen-fixing bacteria and thereby improve soil fertility. The fodder production using small-scale irrigation can help to produce high quality fodder (like vetch) that could improve Ethiopia’s livestock sector and its contribution to the country’s economy.

1.2.5 Suitable fodder production areas using irrigation from shallow groundwater in Ethiopia

Introduction

Developing improved fodder production systems can contribute to poverty reduction goals and thereby enhance social-ecological resilience through building risk buffering assets.

A study (Worqlul et al. 2021) was conducted to evaluate the suitability of lands for selected fodder crops in Ethiopia using groundwater applying GIS-based Multi-Criteria Evaluation (MCE) techniques. Groundwater data from the British Geological Survey (BGS) was used to evaluate the groundwater irrigation potential. The fodder crops selected were Napier (Pennisetum purpureum), alfalfa (Medicago sativa), oats (Avena sativa), vetch (Vicia sativa) and Desho (Pennisetum pedicellatum). The key factors that significantly affect irrigation suitability evaluated include climate (rainfall and evapotranspiration), physical land features (land use, soil and slope), and market access (livestock population and proximity to roads).

Salient findings

Approximately 31% of the country (ca 350,500 km²) is highly suitable for producing Desho, followed by Vetch (23%), Napier (20%), Alfalfa (13%) and Oats (12%). The Abay river basin has the largest suitable area for Napier and oats while the Genale-Dawa River basin has the largest suitable area for Alfalfa, Vetch and Desho.

The suitable area has access to groundwater that could be accessed with simple water-lifting technologies (≤ 30 m from the surface).

Conclusion and way forward

A spatially explicit land suitability map for fodder production in Ethiopia has been produced. There is significant land area suitable for increased fodder production in Ethiopia that can produce sufficient quality and quantity livestock feed. The identified suitable land is situated in areas where there is substantial shallow groundwater accessible using simple water-lifting technologies for small-scale fodder production.

The Abay basin (Upper Blue Nile) has the largest area suitable for fodder production followed by the Genale-Dawa and the Wabi-Shebelle basins.

This study provides valuable insights for decision-makers, practitioners, and the private sector to prioritize and scale fodder production in Ethiopia.
1.2.6 Yield and nutritional quality of sweet Lupine (*Lupinus angustifolius*) grown in mid-altitudes of Lemo District, Hadiya Zone, southern Ethiopia

Introduction

An alternative protein-rich feed resource such as lupins could help address shortage of quality feed. Besides high protein content and digestibility, it has a potential to grow in marginal lands where other food crops do not. Also lupine seed storage and handling are easy as it is hardly attacked by pests.

Adaptability and productivity of forage legumes differ from place to place depending on several environmental and socio-economic factors. Therefore, a study was conducted to evaluate the effect of location, planting spacing and stage of harvesting on the yield and nutritional quality of two sweet lupine varieties (Sanabor and Vitabor released by the Amhara Regional Research Institute). The treatments for the study (Riga et al. 2021) comprised two sweet lupine varieties, two locations (Upper Gana and Jewe Kebeles) and six levels of planting spacing. Although bitter white lupine is a traditional pulse crop in Ethiopia, sweet lupine is a new crop to the country.

Salient findings

Highest green forage yield (39.58 t/ha) and forage dry matter (4.84 t/ha) at 30 cm × 7 cm planting spacing respectively was recorded at Upper Gana Kebele. Seed yield (SYD) (ton/ha) was highly affected (P < 0.01) by location. The maximum seed (2.98 t/ha) yield was observed in Upper Gana Kebele with the minimum (2.15 tons/ha) at Jewe Kebele. The forage in Jewe Kebele had the highest organic matter (OM) (87.01%) and ADF (37.50%) content at a stage of 100% flowering. Sweet lupine forage in Upper Gana Kebele contained the highest CP content (23.1%) while the highest forage CP content was recorded at a planting space of 40 cm × 20 cm (23.7%). Sweet lupine forage gave the maximum IVOMD (69.1%) at a spacing of 40 cm × 20 cm in Upper Gana. The highest CP (29.1%) content and IVOMD (80.5%) of seed were recorded in Upper Gana Kebele.

Overall, green forage yield and forage dry matter yield were affected by location, planting spacing, and stage of flowering, whereas the chemical composition of sweet lupine forage was affected by location and variety interaction (DM and ADF) location and stage of flowering interaction (OM, ADF and total ash), location (CP, ME and IVOMD), planting spacing (CP and IVOMD) and stage of flowering (CP and ME). On the other hand, sweet lupine seed yield, seed CP and IVOMD were affected by location.

Conclusion and way forward

The green forage and forage dry matter yield of lupin varieties were affected by location (Upper Gana produced relatively higher- 4.84 t/ha), planting spacing (30 x 7 cm) and stage of flowering; while lupine seed yield, seed crude protein and IVOMD were affected by location. Sweet lupine has relatively high CP content (21-23%) and a high IVOMD (66-69%). The large differences in yield and nutritive values observed
between sweet lupine varieties, growth environment, planting spacing, stage of flowering and their interactions need consideration for appropriate utilization of sweet lupine as a feed resource for livestock and to obtain optimal seed yield for use as food and feed. Wider dissemination of the results obtained, and demonstration of cultivation practices will help intensive and extensive utilization of lupine as a valued product in Ethiopia. Continual research work on adaptability in different agroecology and animal performance evaluation is recommended. In addition, there is a need to generate information about the nutritional value and physico-chemical and functional properties of the crop parts for human and livestock consumption.

1.2.7 The role of irrigated fodder production to supplement the diet of fattening sheep by smallholder farmers

A farmer participating in the community-based breeding program in Ethiopia, with his fattened sheep. Photo ILRI/Apollo Habtamu

Introduction

There is a distinct seasonality in the availability of feeds in the highlands, reaching peak levels towards the end of the rainy season and critically low levels towards the end of the long dry period when green forage is scarce. This latter part of the year is also the time when the quality of available feeds is at its minimum. The combined effect of feed scarcity and poor feed quality during the dry period presents a serious challenge to livestock owners to meet the energy and nutrient demands of their animals. As a result, the livestock population often experiences cyclic loss of body condition following seasonal feed production patterns, which influences the supply and price of livestock products in the local market.

Small-scale irrigation has the potential to support intensification of the crop-livestock system in the highlands of Ethiopia. Production of improved fodder using irrigation alongside food crops is not
commonly practiced despite the scarcity of green fodder during dry periods. This may be due to lack of awareness, or the impression that production of fodder using irrigation is not economically attractive. However, considering the better price for fattened animals in the dry period and the limitation of fodder during these times, irrigated fodder production combined with fattening may enable farmers to target market niches that generate additional income and diversify their livelihoods.

There is limited participatory research conducted in this regard that could provide farmers the opportunity to assess the benefits of supplemental irrigated fodder production to improve the productivity of livestock and income of farmers.

A study was conducted (Bezabih et al. 2016), wherein farmer groups experimented with irrigated oat-vetch fodder production and sheep fattening, with the aim to: 1) evaluate the performance of irrigated oat-vetch fodder as a source of energy and protein supplement, 2) assess the type and quality of feed resources available for sheep, 3) evaluate the performance of fattening sheep supplemented with irrigated oat-vetch fodder, and 4) examine the potential of off-season sheep fattening as a source of income for smallholders.

**Salient findings**

The biomass yield of irrigated oat-vetch fodder varied from 5.4 to 10 t DM/ha. The variability between individual farmer plots was also considerable. As other green fodder was not available during the dry period, protecting the oat-vetch fodder from roaming animals and pests required extra care and close follow up. The mean crude protein content of the oat-vetch mixture at the time of harvest was 16% on a DM basis, while the metabolizable energy content was 10 MJ/kg DM, suggesting it to be a good supplemental feed.

The mean daily body weight gain of the fattened sheep fed the cultivated fodder ranged from 52-110 grams. The partial budget analysis revealed that while farmers with good feeding management could earn an additional income in the range of 55 – 161 Ethiopian birr (ETB) per sheep, farmers with the lower rate of weight gain could lose up to ETB 58 Ethiopian birr per sheep, if the sale price of sheep remains constant. Sheep prices do fluctuate, peaking during major holiday periods occurring during the dry season. Therefore, timing of the fattening period is essential to profitability, and supplemental irrigated fodder production offers smallholders opportunities to produce good quality feed and target favourable markets for fattened animals to earn higher profit.

Through focus group discussion, it was noted that growing irrigated fodder during the dry period required extra labour to regularly water the fodder plots and that using rope and washer pumps would reduce their labour demand. The green fodder was rarely available during the dry period, and therefore the irrigated fodder was found vulnerable to animal damage and therefore adequate fencing was a necessity.

The feed demand of five sheep was much higher than that of one fattening bull and the farmers found difficult to meet the feed demand of sheep. Moreover, they noted that a bull can be easily tethered and
fed, while five sheep need more labour engagement and regular veterinary treatments. Based on these, most of the farmers (65%) indicated their preference to shift to cattle fattening, whereas the other farmers (35%) preferred to continue with sheep fattening, but with fewer sheep at one time (2-3 per fattening cycle). The latter groups mentioned the ease with which fattened sheep are marketed and the less risk associated with the fattening (in case of death of animals), as a justification.

**Conclusion and way forward**

The irrigated oat-vetch fodder provided good quality green feed supplement to the crop residue based basal diet of the fattening sheep. The fattening practice using the cultivated forage has a potential to generate additional income to the farmers, but the returns are highly dependent on market prices. Market information about the timing of buying (animals to be fattened) and selling (finished animals) is critical for the profitability of the fattening, as there are marked seasonal and inter-market differences in the price of sheep. Farmers need to carefully adjust the timing of the fattening, enabling to bring the fattened sheep to the market when the supply is expected to be low and the prices are high, which usually occur in the dry periods. Irrigated fodder production has an important role in achieving that target by supplying green fodder at the time when feed quality and quantity are major limitations.

Unexpectedly, the feedback from most of the farmers revealed that fattening of five sheep at a time was more labour and feed demanding than that of one bull. Good feeding practices for fattening bulls along with sheep need to be developed and promoted. Furthermore, capacity development on best agronomical practices, including use of irrigated water to produce the oat-vetch fodder and market information system should be strengthened to enhance livestock productivity and income of farmers.

**1.2.8 Tagasaste (Chamaecytisus palmensis) leaf supplementation to enhance performance of sheep in the Ethiopian highlands**

**Introduction**

Crop residues, mainly cereals, have become a major component of the diet of ruminant livestock despite them being fibrous and generally have poor nutritional quality. Supplementation of crop residues with readily fermentable energy and protein concentrate supplements improves their utilization. However, economic constraints and market access under smallholder conditions limit the use of concentrate supplements. On-farm grown leguminous fodder trees and shrubs could be suitable alternatives to supply economically affordable supplements for smallholders. Although several common leguminous fodder trees are well adapted and grow widely in the lowland and midaltitude areas of Ethiopia, their availability in the cooler highland areas is limited due to climatic and edaphic factors. An exception in this respect is tagasaste (Chamaecytisus palmensis L.), which is suited to the cool highland areas (2,000-3,000 m above sea level) of tropical Africa, Australia, New Zealand and Spain. The foliage of this tree is readily consumed by ruminants and contains high concentration of crude protein (18–24%) and digestible dry matter, DM (65–70%). Also it has high biomass yield — up to 10 t DM/ha at about 3 years of age (Assefa 1998). The tree also contributes to soil fertility improvement (fixing about 100 kg N/ha/ year), control of soil erosion,
carbon sequestration, live fence, and bee fodder, which makes it an ideal agroforestry plant in the mixed crop-livestock system.

A study was conducted (Mengesha et al. 2017) to determine the effect of supplementing increasing levels of dried tagasaste (*Chamaecytisus palmensis*) leaf on the nutrition and performance of sheep fed a basal diet of barley straw.

**Salient findings**

In general, intake and digestibility of DM and nutrients (organic matter, crude protein and fibre) increased linearly ($P < 0.001$) as tagasaste supplementation increased from 100 to 400 g/day (20 to 50% of the diet). Likewise, average daily body weight gain increased linearly ($P < 0.001$) from 20 to 73 g/day, feed conversion efficiency from 0.04 to 0.10, and dressing percentage from 40 to 48%, as the supplementation increased from 100 to 400 g/day. The rib-eye area, which is used as an indicator of carcass muscle yield, increased significantly ($P < 0.001$) with the supplementation.

The feed conversion efficiency (FCE) —weight gain to DMI ratio— increased significantly with the supplementation. It is an added advantage, as it lowers the cost of feed per unit of weight gain. The nitrogen (N)-use efficiency (weight gain per unit of N consumed) also increased linearly, from 0.46 to 0.91, indicating lower release of N into the environment with the supplementation.

**Conclusion and way forward**

The supplementation of dried tagasaste leaves up to 50% of the diet dry matter, produced no deleterious effects on the performance of sheep. The inclusion of dried tagasaste at this level can be applied for superior growth performance, carcass yield and carcass quality in sheep fed crop residue-based diets. Increase in FCE and N-use efficiency indicate both economic and environmental effectiveness of the tagasaste leaf supplementation.

Adoption of tagasaste tree cultivation at scale should therefore enable farmers to produce high-quality feed supplement to improve livestock productivity, while at the same time contributing to the ecological sustainability of the mixed farming system in the Ethiopian highlands.

The findings of the study need wider dissemination for increased cultivation of tagasaste tree and use of its leaves as a supplementation to basal diet of barley straw.

**1.2.9 Forage yield and replacing concentrate supplements with oat and vetch mixed forage on the performance of sheep fed Desho grass (*Pennisetum pedicellatum*) based diets**

**Introduction**

The smallholder farmers are often challenged by lack of access and affordability of concentrate supplements for fattening small ruminants. Supplementation of oat-vetch mixed forage, as a substitute for a concentrate, could be an option. An on-farm feeding experiment (Mengistu et al. 2021) was
conducted using yearling rams weighing 21 kg, to evaluate the effect of replacing a concentrate supplement (33%, 67% and 100%) with a home-grown oat-vetch mixed forage on the performance of lambs fed Desho grass basal feed ad libitum. In addition, oat-vetch forage and Desho grass yields were determined.

**Salient findings**

DM yields of the oat-vetch mixture ranged from 6.4-7.1 t/ha and the Desho grass from 10.2-11.8 t/ha.

Feed intake decreased significantly (P < 0.05) with increasing level of supplementation of oat-vetch mixed supplement. Mean daily intake of DM per animal decreased from 742 g for the groups fed on sole concentrate supplement to 691 g for the groups fed on sole oat-vetch supplement. Likewise, the consumption of all other nutrients showed similar pattern to that of dry matter intake.

The groups fed on 67% concentrate plus 33% oat-vetch mixture had significantly higher (P < 0.05) average daily body weight gain (130 g) and feed conversion efficiency (0.17) compared with the others. On the other hand, significantly higher marginal rate of economic return was observed for groups fed on 33% concentrate plus 67% oat-vetch mixture (22.9%), followed by those fed 67% concentrate plus 33% oat-vetch (14.7%).

**Conclusion and way forward**

Under smallholder farmer conditions, it would be biologically efficient and economically feasible to replace concentrate supplement with a mixture of farm grown forages. Oat-vetch mixed forage hay can effectively replace 67% of the concentrate in the intensive sheep fattening practices, without sacrificing production of meat. On-farm forage production (either rain-fed or through irrigation) should improve the availability of the supplemental feed. The feeding of which would boost productivity and profitability by reduction in production coast, elicited by reduced use of expensive and less accessible concentrate feeds. Increased availability of quality seeds of these forages will enhance the sustainability of the livestock production systems.

**1.2.10 Evaluation of replacement value of cowpea (Vigna unguiculata) hay for concentrate mix on performance of sheep fed Napier grass (Pennisetum purpureum) as a basal diet**

**Introduction**

Supplementation of protein-rich concentrates and/or agro-industrial by-products such as oilseed cakes to low-quality tropical grass hay is known to improve intake and digestibility of roughages. However, the use of such protein supplements is limited under smallholder livestock production systems due to their unavailability and high cost. Consequently, there is limited prospect for using such protein-rich feed resources. Forage legumes are alternative protein supplements. Among the forage legumes, cowpea
*Vigna unguiculata* could easily be grown and play an important role in supplementing diets of growing sheep.

In Ethiopia, the small ruminant production systems in different agroecological zones are not studied fully, and farmers’ needs and production constraints have not been identified. Assessment of the small ruminant production system and identification and prioritization of the production constraints is a prerequisite to bring improvement in small ruminant production and productivity in the country. Prioritization of the production constraints helps to use the scarce resources efficiently, and understanding of the production system helps to design appropriate technologies, which are compatible with the system.

A study was conducted (Bedru et al. 2019) to evaluate replacement value of cowpea forage for a concentrate mix on performance of sheep. The concentrate was replaced at levels of 33%, 66% and 100% by cowpea forage fed a basal diet of fresh Napier grass fed *ad libitum*. The treatment used were 300 g concentrate mix (T1), 200 g concentrate mix+100 g cowpea hay (T2), 100 g concentrate mix+200 g cowpea hay (T3) and 300 g cowpea hay (T4) as a supplement to a basal diet. The feeding trial was conducted for a period of 70 days. The feeding and digestibility experiments lasted for 70 days and 7 days, respectively.

**Salient findings**

The average daily gain for T1 and T2 was greater (*P < 0.001*) than T3 and T4. Based on the marginal rate of returns analysis, T3 (184.9%) was superior to other treatments. The highest net benefit was obtained from the use of T2 (555.22 ETB/head), followed by T3 (537.52 ETB/head), T1 (530.63 ETB/head) and T4 (470.50 ETB/head).

The survey findings were that the purpose of keeping sheep and goat was to generate income through sale of live animals, followed by meat production for household consumption and savings. The main constraints for the flock production were outbreaks of disease and parasites, poisoning of livestock due to consumption of toxic plants, feed and water shortage, lack of breeding males, poor extension support and capital. There is a lack of botanical information of the toxic plants existing in the region.

**Conclusion and way forward**

Sheep and goats play an important role in the livelihoods of people in the study area. Through provision of quality feed to them, improving their health management and genetic potential, the contribution of sheep and goats towards enhancing profitability and animal source food consumption can be substantially enhanced. Mortality and morbidity due to consumption of toxic plants is high. It is important to generate botanical information on the toxic plants present in the region and to develop strategies to avoid consumption of such plants by livestock and to enhance knowledge and capacity of veterinarian and para veterinary staff to cure the animals in case of poisoning.
Supplementation of 100 g concentrate mix and 200 g cowpea (33% substitution of concentrate) to a basal diet of Napier grass was found to be more affordable and profitable, and the supplementation with cowpea hay should be promoted. A study on the effect of cowpea hay supplementation on quality of sheep carcass and cow milk should be undertaken.

1.2.11 Simulated economic and nutritional impacts of irrigated fodder and crossbred cows on farm households in southern Ethiopia

Introduction

A farm level economic and nutrition simulation model (FARMSIM) was used to conduct an ex-post study on potential nutritional and economic impacts of the small-scale irrigation technologies on households in southern Ethiopia (Bizimana et al. 2021). The data from the Feed the Future Innovation Laboratory for Small-Scale Irrigation (ILSSI) project, initiated in 2015, was one of the inputs of this simulation study. Other inputs data comprised information on farm assets, liabilities, production costs, yields, output prices and use of crops and livestock products for human consumption and livestock feed. The two scenarios evaluated were the baseline scenario (current) in which fodder (oats and vetch) is grown on limited land with minimal irrigation and fertilizer, and the alternative scenarios in which more land, fertilizers and water (through irrigation) and improved seeds were allocated to fodder during the dry season. Also, the crossbred cows were raised in the alternate scenarios. In the former system all the fodder produced was sold at the market for revenue generation due to limited production, and in the later a portion of the total production of fodder was fed to cows, bulls and sheep to increase the production of milk and meat, and the remainder was sold to generate income.

Forecasting was done for the five-year period. Annual net cash income (profit) and the benefit cost ratio were some of the economic key output variables, while the nutrition variables included average daily intake of calories, protein, fat, calcium, iron and vitamin A for an adult equivalent.

Salient findings

Small-scale irrigation technologies can be used to grow irrigated fodder and vegetables in the dry season for households to generate income and improve nutrition. The introduction of crossbred dairy cows has the potential to produce three times more milk than local cows, and its introduction further increased the income.

Although the production of vegetables and animal feeds in the dry season, increased the costs of production, households under alternative and improved small-scale irrigation technologies generated more income than their counterparts in the baseline scenario. The annual average profit under alternative scenarios was almost twice that of the baseline scenario. However, the distribution results highlighted the risk associated with the costs of high production and water lifting tools (e.g. solar pump) from the investment of SSI technologies.
The nutritional analysis showed that the quantities of crops and livestock products consumed by families in both the baseline and alternative scenarios met the minimum daily requirements for calories, proteins, iron, and vitamin A, but not for calcium and fat. However, forgoing some income (from selling of the animal products) to increase the quantity of animal products consumed at home, led to the increase in available proteins by 12%, fat by 24%, calcium by 73%, iron by 5% and vitamin A by 17% under the alternative scenarios with improved livestock production technologies and purchase option.

Simulation results show that the increase in animal products availability can potentially lead to higher consumption of animal products at the household level and increased nutrient intake, improving the overall nutritional status and food security.

**Conclusion and way forward**

Small-scale irrigation technologies can be used to grow irrigated fodder and vegetables in the dry season for households to generate income and improve nutrition. Introduction of cross-breed animals also increased the profit because of its higher potential (three times) for milk production than the local cow. Increase in production of vegetables along with fodder during the dry period was also found to be more profitable, though it increased the cost of production.

In addition to the economic benefits of the improved technologies, the nutritional impacts could be significant, provided the farm families or households increase consumption of their own produced products especially animal sourced food. The adoption of improved agricultural and livestock technologies has a high potential to improve economic and nutritional wellbeing and resilience in Ethiopia, and it offers an opportunity to meet its economic development and food security goals.

Given the current circumstances and future scenarios, rainfed fodder production alone will not be enough as land will continue to be in short supply. Use of small-scale irrigation to grow fodder during the dry period is an important strategy to overcome such land constraints. Therefore, a combination of rainfed and irrigated fodder production together with improvement in animal genetics is expected to help intensify livestock production considerably in the smallholder system.

The results of this study present a strong case for decision makers and development partners to invest in small scale irrigation technologies, forage development and livestock production.

**1.2.12 Environmental co-benefits of improved tropical forages for an agroecological transformation of livestock production systems**

**Introduction**

Livestock are critical for incomes, livelihoods, nutrition and ecosystems management throughout the global south. Livestock production and the consumption of livestock-based foods such as meat, cheese, and milk are, however, under global scrutiny for its contribution to global warming, deforestation, biodiversity loss, water use, pollution and land/soil degradation.
Although the environmental footprint of livestock production presents a real threat to planetary sustainability, also in the global south, this is highly contextual. Under certain context-specific management regimes livestock can deliver multiple benefits for people and planet.

A study (Notenbaert et al. 2021) explained the multi-functionality of cultivated forages and provided an overview of where and to what extent the forages have been applied and how this has benefited people and the planet alike. The study further examined their potential to contribute to the 13 principles of agroecology and find that integrating cultivated forages in mixed crop-tree-livestock systems follows a wide range of agroecological principles and increases the sustainability of livestock production across the globe.

**Salient findings**

A move toward sustainable intensification of livestock production is possible through promotion of cultivated forages. It could mitigate negative environmental impacts and even provide critical ecosystem services, such as improved soil health, carbon sequestration and enhanced biodiversity on farms. Livestock production in the tropics based on improved forages can boost the sustainability indicators of this system, moving toward an agroecological transformation of the food system.

**Conclusion and way forward**

The use of cultivated forages including grasses, legumes and trees (many improved through selection or breeding), in integrated crop-tree-livestock systems is a steppingstone toward agroecological transformation. More research is needed at the food system scale to fully understand the role of forages in the sociological and process aspects of agroecology. The research makes the case for further genetic improvement of cultivated forages and strong multi-disciplinary systems research to strengthen our understanding of the multidimensional impacts of forages and for managing agro-environmental trade-offs. Further action is needed for the agroecological and livestock research, and for the development communities to improve communication and join hands for a sustainable agri-food system transformation.

**1.2.13 OVERALL CONCLUSION, LESSONS LEARN AND WAY FORWARD**

The primary constraint for increasing livestock production is the lack of quality feed. One of the ways to alleviate this constraint is to increase availability of good quality forages. The dry matter yield of cultivated forages and their quality are much higher than the naturally growing pastures. The factors that limit production of quality forages in Ethiopia has been the poor availability of quality seeds and planting materials, and non-application of good agronomic practices due to lack of knowledge and skills of the farmers. Increased cultivation of forage crops might result in land competition for food crop production. This can be decreased by using quality seeds and planting materials and use of best agronomic practices that increase forage yield per unit area, and through introduction of legume forages that can be integrated with other cropping systems. Towards this end, several studies were undertaken through the CRP.
The cultivated grasses in general have been favourably accepted by farmers. Napier grass was the highest yielding grass in terms of dry matter and nutrient yield, while Brachiaria and Desho grass varieties provided alternative options with better fodder quality. The hybrid Brachiaria grasses have a high CP content (> 18%), suggesting these to be good feeds for use as a supplement to other local feed resources, for example Napier grass, Desho grass and crop residues. Brachiaria Mulato II is a better forage than Brachiaria Mulato I in terms of dry matter and nutrient yield. Also, farmers highly value the leafiness and softness of Mulato II compared to the other grasses. However, a close follow up and management is needed to overcome the spider mite pests, which pose a challenge to both the hybrid Brachiaria grasses.

The key determinants of survival and growth of tree lucerne (e.g. higher survival of tree lucerne on-farm in backyards and for middle-resource class households and decreased survivability by browsing) and the lessons learnt (e.g. proper management of the plant at the establishment phase), identified through the research, would help in large-scale adoption of tree lucerne. A dry matter yield of 8-14 tons/ha could be achieved. The supplementation of dried tagasaste (tree lucerne) leaves up to 50% of the diet dry matter results in superior growth performance, carcass yield and carcass quality in sheep fed crop residue-based diets. Furthermore, the observed increased feed conversion efficiency and nitrogen-use efficiency indicate both economic and environmental effectiveness of the tagasaste leaf supplementation. The wider propagation and use of this tree as animal feed has been achieved through AFRICA RISING Project. Additional follow up research on determination of cutting frequencies and feeding of the forage with various local feed resources to targeted livestock species would help achieving full potential of this multipurpose fodder tree. In addition, particularly targeting and working intensively with the medium-resourced farmers with a fair amount of land and livestock, who can readily apply essential pre- and post-planting management practices would help in early adoption of tree lucerne. The findings will also be valuable inputs for future research and development initiatives on the integration of fodder tree species into crop-livestock systems.

Availability of water enhances productivity of cultivated forages. A spatially explicit land suitability map for fodder production in Ethiopia have been produced. There is a significant land area suitable for increased fodder production in Ethiopia that can produce sufficient quality and quantity livestock feed. The identified suitable land is also situated in areas where there is substantial shallow groundwater accessible using simple water-lifting technologies for small-scale fodder production. The Abbay basin (Upper Blue Nile) has the largest area suitable for fodder production followed by the Genale-Dawa and the Wabi-Shebelle basins. These findings provide valuable insights for decision-makers, practitioners, and the private sector to prioritize and scale fodder production in Ethiopia.

Another study conducted through the CRP illustrated that there is a substantial amount of water resources in watersheds to produce fodder production using small scale irrigation. This study also showed that the average optimal amount of water required to cultivate Napier and a mix of oats and vetches is around 550 and 250 mm, respectively. For oat and vetch production, the poor soil fertility, particularly low phosphorus level is one of the major yield-limiting factors. Although biomass production per unit area is higher for Napier grass than oat-vetch mix (ca 18 vs 5.4-10 t DM/ha), the oat and vetch contain highest
crude protein and energy content (16% on dry matter basis and 10 MJ of metabolizable energy/kg dry matter respectively), and the mix provides a superior nutrition to the livestock. Also, these legumes have substantially high biomass production and fix nitrogen and improve soil fertility. The irrigated oat-vetch fodder provides good quality green feed supplement to the crop residue based basal diet, resulting in higher growth in the fattening sheep.

Some forage production studies were integrated with the animal feeding studies that evaluated their nutritional value and profitability. Effects of feeding cultivated forages to small ruminants have been encouraging. The studies showed that the fattening practice using the cultivated forage has a potential to generate additional income for the farmers, but market information about the timing of buying for animals to fatten and the timing of selling the finished animals is critical for the profitability of the fattening, because as there is a large seasonal price variation. The prices of the finished animals are usually high in the dry periods. A spill over result of the sheep fattening studies was the interest shown by the farmers to fatten bulls along with sheep. This highlights the need to develop good feeding practices for fattening bulls as well and to promote the practices. Likewise, oat-vetch mixed forage hay can effectively replace 67% of the concentrate in intensive sheep fattening practices, resulting in reduction in the cost of feeding and increase in profitability.

Sweet lupine has relatively high crude protein content (21-23%) and a high organic matter digestibility (66-69%). Agronomical practices have been optimized for the two sweet lupin varieties with the aim to enhance forage production. These need consideration for appropriate utilization of sweet lupine as a feed resource for livestock and to obtain optimal seed yield for use as food and feed. Wider dissemination of the results obtained, and demonstration of cultivation practices will help intensive and extensive utilization of lupine. Continual research work on adaptability in different agroecology and animal performance evaluation would help scaling-up the lupin as a protein-rich feed resource in Ethiopia. Cowpea forage, having similar nutritive value as lupin forage, when fed at 33% substitution of concentrate and Napier grass as the basal diet, improved growth rate and profitability.

The results of the AFRICA RISING project suggested that the cultivated forage crops were more variable in terms of uptake. Desho grass was widely adopted (74% farmers increased its use), while oat and vetch did not achieve such a widespread uptake (53% farmers increased their use). Sweet lupin was not widely used. The use of Napier grass was widespread. It is important to understand the reasons for adoption or non-adoption of the cultivated forages. Future efforts to promote cultivated forages should take note of the lessons learnt from the experiences of the AFRICA RISING project. Some approaches, emanated from the AFRICA RISING work, that could enhance adoption are:

1) **Continuous follow up and interaction with farming communities.** Partnership with local organizations, establishment of innovation platforms, presence of site coordinators, organization of various cross learning capacity building events and conducting annual review and planning meetings contributed to the follow up and implementation of planned feed and forage innovations. The continuous follow up
approach has also assisted in drawing lessons and identifying challenges that have emerged while implementing the feed and forage innovations.

2) **Demonstration of integrated feed and forage innovations.** Demonstration of forage innovations together with post-harvest feed management and utilization practices at central locations such as farmers training centres and selected fields of innovative farmers improved their visibility and acceptability by farmers and extension workers. Formation of farmer research groups based on farmers interest and priority, and organization of periodic group visit for farmers was found to be useful to enhance innovation and cross learning.

3) **Flexibility of feed and forage technological options.** Adaptability of a technology depending on the situation helped in the adoption. An example being use of feed troughs that accelerated acceptance and adoption by smallholder farming communities. Farmers in the different project sites modified the feed trough technology in several ways depending on their needs, economic capacities and ecological conditions. *Inadequate supply of seeds was a major challenge for scaling of forage innovations.* Strengthening of formal forage seed sector must be given priority in the livestock sector development agenda of the government and donors. Effective public-private partnerships could play an important role in forage seed production and distribution.

The conclusions drawn from the production and feeding studies on forages (e.g. Napier grass, Brachiaria hybrids, lupin, cowpea, tree lucerne, oat and vetch) should be widely disseminated. Effective integration of cultivated forages in the smallholder crop-livestock system requires demonstration and promotion of suitable and context specific forage genotypes as well as agronomic practices. These grasses may be propagated after understanding farmers’ requirements and production objectives because the use of Napier and Desho grasses is largely as a basal diet, and these would require supplementation of protein-rich feeds to achieve high animal productivity. The protein-rich feeds could be concentrates or forages from Brachiaria, lupin, cowpea, oat, vetch and tree lucerne. These protein-rich forages could also be used as a supplement to low quality crop residues and this combination has potential to support high producing animals. The project activities focused largely on small ruminants. Nutritional, economic and environmental analyses of feeding quality forages to milking cows should be conducted.

Irrigated fodders can be cultivated on a substantial area in Ethiopia. The small-scale irrigation can help to produce high quality fodder that could improve Ethiopia’s livestock sector and its contribution to the country’s economy. The dry matter yield of cultivated forages is eight to ten times more and their quality two to three times higher than the naturally growing pastures. The cultivated forages play an important role in supplying green fodder at a time when feed quality and quantity are major limitations. Their adoption enables farmers to produce high-quality feed supplement to improve livestock productivity, while at the same time contribute to the ecological sustainability of the mixed farming system in the Ethiopian highlands.
Given the future scenarios, rainfed fodder production alone will not be enough due to increasing shortage in land availability. Use of small-scale irrigation technologies to grow forages during the dry period will enhance forage productivity and therefore is an important strategy to overcome land constraints. Introduction of cross-breed animals in the setting where forage has been cultivated using irrigation would increase the profit because of their three-times higher potential for milk production than the local cows. A combination of rainfed and irrigated fodder production together with improvement in animal genetics is an attractive option for intensification of livestock production. Enhanced investment in small scale irrigation technologies, forage development and livestock production must be the focus of donors, governments and private sector.

The environmental co-benefits of improved tropical forages suggest that the use of cultivated forages, including grasses, legumes and trees in integrated crop-tree-livestock systems could be a stepping-stone toward agroecological transformation of the livestock production systems. However, more research is needed at the food system scale so that the role of forages in the sociological and process aspects of agroecology, including agro-environmental trade-offs could be fully understood.

For farmers to successfully grow tree lucerne or other so-far-not used forages on their farms, researchers, extension workers and farmers must work jointly to identify leverage points for integrating them in existing farming systems and capacitate local farmers on their management. Backstopping farmers through the formation of research groups is a useful approach to enhance innovation and cross learning. Adoption by farmers is likely to be easy if they can learn by seeing. A targeted approach could therefore create a learning centre in each action site, from which others could receive experience and adapt the required management practices.

This approach has been used in AFRICA RISING project and has had a high impact towards application of cultivated forages. Transition from forage research to scaling requires an array of complementary sets of actions. The combination of the action research approach, demonstration of technologies at farm conditions, engagement in multi-stakeholder platforms, joint planning and review of field activities and capacity building of local partners are crucial in progressive transitioning from research for development activities to a wider scale adoption.

These approaches help local partners to own the forage innovations and to tap into financial resources to scale them. Furthermore, wider scaling of forage innovations requires a continuous effort to capitalize on existing opportunities and continually build an enabling environment. Some of the actions could be linking the forage innovations to market pulls (i.e. to output-oriented livestock products such milk and meat production), strengthening the role of farmer organizations in forage supply, addressing systemic constraints facing private forage seed suppliers, improving the regulatory environment through initiatives such as forage seed certification and supporting a progressive transition from the current free handout of forages and forage seeds towards market-led business models.
Sheep and goats play an important role in supporting the livelihoods of people, and sheep and goat productivity can be substantially enhanced through provision of quality feeds. However, need is to put in place a holistic approach in which not only animal nutrition is enhanced but also disease management, housing and genetic potential of animals, and marketing of animals and animal products are addressed. To realise this, some future options identified in the Ethiopian context are: 1) increased attention of development actors and partners to strengthen veterinary services including training, credit facilities, and formation of farmer cooperatives to facilitate drugs supply and distribution, to reduce losses due to diseases, 2) efficient delivery of inputs including forage seeds and planting materials and of improved technologies relevant to the smallholders, and 3) strengthening of marketing infrastructures, and delivery of market and price information for efficient marketing.
1.3 USE OF CACTUS AS A MULTI-PURPOSE CROP IN MIDDLE EAST, NORTH AFRICA AND SOUTH ASIA AND OF HIGH-QUALITY CASSAVA PEEL MASH IN AFRICA

In quest for further enlarging feed resource base, this section presents potential and opportunities for exploiting an unconventional feed resource, cactus. The work on cactus was driven by ICARDA. ICARDA’s Rangeland Ecology and Management Unit aims to address the unsustainable use of resources induced by adverse effect of climate change and an increasing demand for food and feed in the dry areas. ICARDA programs promoted the enhanced quality and productivity of crop, forage, livestock, and the improved management of water resources through close cooperation with farmers and national researchers. Under this program, one of the plants on which extensive research and development was conducted has been cactus (Opuntia ficus-indica (L.) Mill). Scientists at the ICARDA were the first to research and scale up cactus pear as a crop that can be easily cultivated and utilized by millions of farmers in dry regions to improve nutrition, provide fodder reserve, and boost livelihoods.

Cactus pear, known in some desert areas as ‘green gold’ for its many uses, has great potential to improve productivity in arid and semi-arid areas. The Crassulacean Acid Metabolism photosynthetic system results in traits that are adapted to tolerate severe drought conditions. This makes cactus pear an ideal ‘drought insurance’. Due to its shallow and widespread root system, the plant is willing to exploit limited rainfall to its fullest potential. Cactus pear can provide feed; it can produce a large quantity of palatable green forage in the most difficult seasons throughout the year; and it also provides much needed energy, minerals and vitamins. The succulent cactus cladodes (pads) also serve as a source of water for livestock in the dry areas.

ICARDA’s program on cactus can be grouped under six main categories:
1) Characterisation and evaluation of germplasm
2) Promoting best agronomical practices,
3) Cactus as a feed,
4) Capacity development and dissemination,
5) Changing perception and adoption
6) Rangeland rehabilitation and ecosystem goods and services.

Some major publications in each of these areas are synthesised below. This is followed by a section that contains overall conclusion and lessons learnt.

### 1.3.1 Characterization and Evaluation of Germplasm

Under the collaboration program between the National Centre for Agricultural Research (NARC) in Jordan and ICARDA, more than 100 accessions of cactus pear were introduced and planted in Muchaqqar research station, Jordan between 2013 and 2017. These accessions have different genetic characteristics in terms of productivity, specifications and purpose of use, and were collected from different countries including Italy, Brazil, America, Argentina, Tunisia, Morocco and Mexico. This activity was sponsored by the Arab Fund for Economic and Social Development (AFSED). There are different accessions for fruit production which showed good performance. They produce fruits with different flavours and colours, ranging from red to yellow to green. Also, they vary in terms of productivity and maturity date — there are early, moderate and late maturity accessions. These new cactus pear accessions offer an opportunity to help farmers to diversify their products and income.

#### 1.3.1.1 Morphological characterization of cactus pear (*Opuntia ficus-indica*) accessions from Agadir, Morocco

**Introduction**

The North Africa region falls under an arid or semi-arid climate and is considered as a hot spot for climate change. To combat feed shortages, increase the income of the rural poor and mitigate the effect of climate change, around one million hectares of cactus crop have been planted in Tunisia, Algeria and Morocco. Aware of the importance of germplasm, ex-situ collections are being initiated in the region, where promising accessions have been introduced from many countries.

A study (Nefzaoui et al. 2019) was conducted to assess the genetic diversity of 20 cactus pear accessions from the ex-situ collection located at the Institut National de la Recherche Agronomique (INRA) Morocco research station in Agadir using morphological characterization based on FAO Cactusnet descriptors. The data were subjected to principal component analysis (PCA) and agglomerative hierarchical clustering (AHC) using the XLSTAT 2015 package.

**Salient findings**
The accessions can be discriminated by some of the morphological characteristics. Many of these characteristics were significantly correlated, such as number of cladodes and number of fruits \((r=0.73)\), number of cladodes and plant diameter \((r=0.73)\), length of the cladode and plant height \((r=0.7)\), length of spines and number of areoles \((r=0.67)\). Cladode shape and the number of spines and areoles are the recommended traits, since they were capable of discriminating accessions with suitable accuracy. Other descriptors do not seem to influence the morphological characterization, including cladode thickness, number of spines, plant height, and cladode shape index. Therefore, PCA and AHC are efficient tools for segregating accessions using a reduced number of morphological characteristics. Another important finding is that the number of morphological characteristics may be reduced without potential risk of reducing the accuracy of the phenotypic characterization for this collection and location.

**Conclusion and way forward**

The PCA and AHC are efficient tools for segregating accessions using a reduced number of morphological characteristics. Cladode shape and the number of spines and areoles are capable of discriminating accessions with suitable accuracy. The use of these tools is suggested for further studies on identification of promising cactus pear accessions.

**1.3.1.2 Screening for cold tolerant cactus species \((Opuntia ficus-indica)\) under west Asian conditions**

**Introduction**

Cactus pear has developed phenological, physiological and structural adaptations to the arid areas characterized by drought, erratic rainfall and poor soils. It has gained an important place in the agricultural systems as a fruit, forage and fodder provider, particularly in subsistence agriculture where it can grow with minimal agronomic inputs and its tolerance to drought. Despite the great capacity for adaptation and their ability to grow in harsh environments, which are not favourable to produce most common crops, frost risk can be considered as one of the major limitations to cactus growing in the West Asia-North Africa (WANA) region as well as in many parts of the world.

Using a randomized complete block design (RCBD) with five replicates, 42 accessions of cactus pear \((Opuntia ficus-indica)\), imported from various locations (North Africa, Italy and Mexico), were planted in April 2013 in Muchaqqar Research Station, Jordan. The evaluation took place over winter, from 2015 to 2017 (Louhaichi and Hassan. 2018).

**Salient findings**

Significant differences in cold/freezing tolerance, cladode number per plant and cladode fresh weight (grams), and average cladode weights among the tested cactus pear accessions were detected \((P<0.01)\). COPENA V1, 74115_Bab Toza, and 74001 cultivars produced the highest number of cladodes per plant, accessions 69223_Burbank Azrou, 2_25_15 and Bianca de Bonacardo demonstrated the most frost...
tolerance and accessions 69242_Matmata, 69246_Oueslatia, and COPENA V1 recorded the highest cladode average weights.

**Conclusion and way forward**

Results from this study would help in promoting the adoption of cold resistant cactus accessions, and potentially improve livestock production and create alternative income generation options for resource poor farmers in arid regions of west Asia.

1.3.1.3 Evaluation of morphological and chemical characteristics of spineless cactus pears under the environmental conditions of Qatar

**Introduction**

Cactus can grow with minimal agronomic inputs, and its tolerance to drought is high. These traits make cactus a suitable crop for the arid and semi-arid regions. Cactus pear has developed several adaptations to the arid and semi-arid areas.

A study (Wawi et al. 2019) was conducted to evaluate 38 spineless cactus pear accessions (*Opuntia ficus-indica*) introduced to the research station of Rodhat Al Faras in Qatar. These accessions were planted and assessed for their morphological properties (growth, shape and colour of the cladodes etc.) and chemical composition (contents of protein and minerals) during two growing seasons (2011-2013).

**Salient findings**

Highly significant differences between the studied accessions in all morphological parameters were observed. The number of cladodes was 29.4 per plant on average and their mean length, width and thickness were about 36.3 cm, 18.3 cm and 0.8 cm, respectively. Statistical analysis also showed large significant differences at the level of cladode chemical composition, except for calcium and phosphorus ($P>0.05$). High variability in chemical composition parameters of cactus pear accessions was observed. Sbeitla accession had the lowest protein concentration (7.9%). On the other hand, Bargou accession had the highest protein concentrations (13.5%), which may exceed the protein concentration of some irrigated forage grasses cultivated in Qatar.

**Conclusion and way forward**

This study recommends the selection of cactus pear accessions that combine plants with high productivity and quality. The Tunisian accessions showed the best reproductive and productive performance and would be recommended for dissemination on a large scale in private farms. There is a need to continue monitoring the performances of these accessions in research stations and farmers’ fields.
1.3.1.4 Evaluation of cactus accessions across different agro-ecological zones to enhance establishment of cactus orchards

Introduction

The demand for cactus pear cultivation is increasing worldwide, but it is necessary to respect the requirements and level of adaptability of the available genetic resources to different growing regions.

A study (Louhaichi et al. 2020a) was conducted to evaluate the performance of 68 accessions that were planted in Al-Karama Agricultural station (NARC Station) located in south of the Jordan Valley (31° 55' 50.05" N 35° 34' 11.89" E).

Salient findings

A 100% survival rate was observed in more than 50% of the cactus pear accessions followed by 80% survival rate was recorded by 30% of the planted cactus pear accessions. Only two accessions (32_Matmata_69242 and Algerian 3/2) recorded low survival rate 40% and 20% respectively. A full list of 68 accessions is available in the reference cited for this study.

The plant height ranged between 20-77 cm, average 44 m; plant condition score varied between 1.8- 5, average 3.45; and the range of cladodes number was 1-10; average 6. Blue Motto was the highest with greatest number of cladodes, while 2_Leavis SP5_74112 accession expressed the best plant performance. A considerable number of accessions (47%) generated cladodes higher than the average. There were significant correlations (P < 0.001) between plant height and both plant condition and number of cladodes, and for plant condition and number of cladodes.

Conclusion and way forward

Significant differences were found between cactus pear accessions under Jordan valley environmental conditions. The cactus pear accessions recorded high survival rate and they differed significantly in the plant height, plant conditions and number of cladodes. A set of accessions have been identified that has the highest adaptability to the Jordan valley environment. These form a good basis for providing resources that can be grown well under different environmental conditions.

Further trials are needed to evaluate existing cactus germplasm across the Kingdom of Jordan, in particular where drought and salinity conditions are prevalent. Future studies should lead to generation of a land suitability map for cactus cultivation across Jordan based on spatial distribution of climatic and edaphic factors.
1.3.1.5 Morphological and chemical composition characteristics of cactus pear accessions under west Asian conditions

Introduction

To identify the right accessions for the right places, a study (Louhaichi et al. 2020) to assess the performance of 33 cactus pear accessions planted in Mushaqqar research station, Jordan was conducted using morphological and chemical composition characteristics.

Salient findings

A very high level of morphological and nutritional composition variability among cactus pear accessions. A significant variation in amount of ash and the content of Ca, Fe, Zn, Cl, P, Na and K (P< 0.001) existed. Gialla di sarrocrh (GSH) accession contained the highest contents of Ca and Na. Zn content was highest in Italian accession Tunzara Bianca San Cono. Mezzojuso accession was the richest in Fe and phosphorus contents (0.23 ± 0.023 ppm, 8.56 ± 1.028% respectively). V1_ COPENA V1 accession ranked first in Cl, K and ADF contents. The crude protein content of all accessions was less than 6.1 %. Max Fodder_1278 produced the highest number of cladodes with highest content of fibre.

Conclusion and way forward

The observed high variability will be very useful for the cactus pear utilization programs in the west Asian region. Future studies using molecular markers could further improve selection of right accessions.

1.3.2. PROMOTING BEST AGRONOMIC PRACTICES

For large scale promotion of the cactus, agronomic conditions need to be optimised for the promising accessions, identified through a systematic screening process. Several studies were conducted in different regions in west and south Asia, Middle East and North Africa.

1.3.2.1 Cactus productivity, composition and soil parameters as affected by agronomic management in a semi-arid region of India

Introduction

Cactus pear has proven its potential to contribute to minimizing green fodder shortage despite its relatively recent introduction into India. Study of appropriate planting time and response to agronomic management practices is imperative for the newly introduced cactus pear (Opuntia ficus-indica (L.) Mill.) into a semi-arid region of India. Responses of cactus pear to agronomic practices (planting time and irrigation and fertilizer application) were evaluated (Kumar et al. 2021) to determine the potential for fodder production and livestock feed in a semi-arid environment of India. Four planting times (February, March, July and October) and two agronomic managements (with and without irrigation and fertilizer application) were evaluated during 2016–2020 in Jhansi, India.
Salient findings

Cactus pear establishment and growth improved with planting time in July and October due to favourable soil moisture and congenial temperature. However, plant height (130.1 cm) and cladode weight (914 g) were greater in July than in the October planting period. Nutrient uptake and crude protein contents, however, were higher for the earlier plantings of February and April compared to June and October. Irrigation and nutrients application had little effect on the cactus pear plant growth, except on plant width and cladode length and width.

Conclusion and way forward

Cactus pear can be planted during July in moderately fertile soils without any agronomic intervention in semi-arid situations of India. It has potential as an effective alternative source of forage for livestock during the summer months. Use of these practices in further promoting cactus in semi-arid regions of India is suggested.

1.3.2.2 The effect of soil volume availability on *Opuntia ficus-indica* canopy and root growth

Introduction

The relative growth of roots and canopy, in terms of the root/canopy ratio, changes greatly with plant age and environmental conditions since the growth rates of roots and canopy continually adjust to resource availability and sink demand. The study (Hassan et al. 2020) investigated the effect of soil volume
restriction on the below- and above-ground growth of *Opuntia ficus-indica* through understanding the limit imposed by root confinement via different soil volumes on root and canopy architecture and growth.

**Salient findings**

The soil volume restriction can substantially reduce the root and canopy growth of *O. ficus-indica*, in terms of surface area and dry matter accumulation, as well as total root length and volume. This reduction was associated with a lower cladode number but an increased root turnover. The soil volume decrease impacted the growth and the surface area of the main roots negatively, while there was an increase in the fine lateral root growth in the soil volume unit, specific root length, root density, as well as root length density. The more lateral roots and finer root system per soil volume of *O. ficus-indica* seem to be a kind of adaptive strategy to enable the plants to sustain and increase the root surface area to increase, improve and explore new nutritive resources. Eventually, it seems that cactus pear plants growing in soil volumes lower than a critical point for optimum plant development may shift their resources allocation from vegetative growth to starch accumulation in the cladodes and in the roots, to enhance the root turnover rate.

**Conclusion and way forward**

The results confirmed the importance of *O. ficus-indica* as a potential plant that can survive under low soil volume conditions. This plant can balance its growth and stay alive under harsh environments. Further experiments are needed to investigate the role of plant nutrition and particularly the role of organic nutrition (manuring) on plant growth and development under conditions of limited soil resources.

**1.3.2.3 Root growth and soil carbon turnover in *Opuntia ficus-indica* as affected by soil volume availability**

**Introduction**

A study (Hassan et al. 2019a) was conducted to investigate the effect of soil volume restriction, i.e. root confinement, on below-and-above ground growth of cactus pear (*Opuntia ficus-indica* (L.) Mill) as well as the effect on root architecture and turnover, and soil carbon turnover.

**Salient findings**

Results indicated a significant effect of soil volume and sampling dates on total root length, root dry mass and δ13C. The data showed a linear positive and significant effect of the soil volume on the large and fine roots mass. Roots of the plants placed in the smallest soil volume had higher C root turnover (% per year), and soil organic carbon (SOC) showed a significant increase in relation to sampling dates, spread from 6 to 24 months.

**Conclusion and way forward**
Cactus pear could enhance accumulation of SOC in soils. Cactus cultivation on degraded soils would enhance soil carbon status.

1.3.2.4 The effect of soil volume on the growth of roots and canopy of *Opuntia ficus-indica*

*Introduction*

The influence of soil volume on root development and canopy growth rates of cactus pear (*Opuntia ficus-indica*) was studied (Hassan et al. 2019b) at Palermo University, Italy, in 2014-2016. In November 2014, 60 1-year-old *O. ficus-indica* cladodes were planted in pots containing five different soil volumes, 50, 33, 18, 9 or 5 Litres, in a complete randomized design with three replications. Root dry mass, total number of cladodes and canopy dry mass were measured after 6, 12, 18 and 24 months.

*Salient findings*

A significant effect of soil volume and sampling time and their interaction (P<0.01) on root dry mass, total number of cladodes and canopy dry mass was observed. Root dry mass ranged between 23-206 g, with the highest value for plants grown in 50 L soil volume, sampled after 24 months of planting. The highest number of cladodes was produced by the plants raised in the highest soil volume (50 L) after 24 months of planting and the lowest number was in the lowest soil volume (5 L). A linear increase in canopy dry mass was observed with respect to increased soil volume. Increased soil volume had a significant and positive effect on the roots to canopy dry mass ratio.

*Conclusion and way forward*

The restriction of soil availability in *O. ficus-indica* resulted in major growth limitation for root and canopy. Restriction of soil availability should be avoided for optimal growth of cactus.

1.3.2.5 Promoting the Use of Cactus Pear in India: effect of organic manure and irrigation applications

*Introduction*

Smallholder farmers in semi-arid environments have limited resources to improve the supply of animal feeds. Cactus pear (*Opuntia ficus-indica*) is an ideal candidate that can grow in degraded land with minimum inputs. However, proven agronomy best practices under these conditions are needed.

The experiment was conducted at the Food Legume Research Platform-ICARDA, Amlaha in Bhopal located in Madhya Pradesh. The objectives of this study (Hassan et al. 2019c) were to evaluate the effect of planting date on cactus pear canopy development and yield and to evaluate the effect of organic manure and supplemental irrigation applications on cactus pear yield.
**Salient findings**

Planting in mid-July resulted in the highest total number of the cladodes, and dry matter production was highest for both treated and control plants. Mid-February and mid-April planting dates led to the lowest number of cladodes and dry matter production for the control and treated plants respectively. Except from the mid-July planting date, the effect of organic manure and supplemental irrigation application significantly increased the total number of cladodes and the dry matter per plant.

**Conclusion**

Supplemental irrigation with organic manure application can enhance the productivity of cactus pear

**1.3.2.6 Manual: Cactus pear agronomic practices**

A manual of good agronomic practices for cultivation of cactus pear has been developed by ICARDA. The manual covers topics including site selection, planting date, planting methods, plant spacing, planting in pits, planting in furrows, planting, cactus pear planting, weeding management, irrigation, fertilization, pruning, fruiting and cactus plant parts as animal feed. It is available both in English (Louhaichi et al. 2019a) and Arabic (Louhaichi et al. 2021a).

This manual is being used by many farmers, development and extension workers, researchers and students.

**1.3.3 CACTUS AS A FEED**

One of the important uses of cactus is as livestock feed and a number of feeding studies were conducted under the ICARDA programme to evaluate its potential as a feed.

**1.3.3.1 Assessment of different supplemental feeding strategies including cactus (Opuntia ficus-indica) to enhance sheep productivity in Chakwal, Pakistan**

**Introduction**

In arid and semi-arid areas, livestock production is faced with a challenge of uncertain feed supply which limits the quantity of forage available to animals either from natural grazing or crop residues. A study (Islam et al. 2019) compared the effect of three different supplemental feeds including oat (Avena sativa L.), lucerne (Medicago sativa L.) and spineless cactus (Opuntia ficus-indica (L.) Mill.) in addition to a control treatment (farmer practice without supplementation) on sheep productivity, over a 60-day period in Chakwal, Pakistan. The common ingredients of the three diets were maize grain, barley grains, wheat bran, canola meal, groundnut hay and wheat straw.
**Salient findings**

Lactating ewes fed oat (0.076 kg per day) and lucerne (0.064 kg per day) supplements showed similar average daily gain (ADG) compared with cactus- and control-supplemented ewes, with the same trend observed for dry ewes. The ADG for lambs fed cactus and lucerne was greater (at 0.083 kg per day for both), compared with those fed oats and the control treatment. Weight changes of lactating ewes fed with different supplement feeds were not significantly different over the course of the experiment. Dry ewes supplemented with cactus had greater weight gains (54 kg at 15 days of supplementing and 57 kg at 60 days of supplementing) compared with oat-supplemented dry ewes (46 kg and 50 kg) from the first weighing interval until the end of the experiment.

**Conclusion and way forward**

The supplementation of sheep with cactus has a positive impact on live-weight gain, compared with solely grazing under poor rangeland conditions. Therefore, it is important to develop rations that maximize the full potential of this low-nitrogen, yet water- and carbohydrate-rich alternative feed source.

1.3.3.2 Nutrient intake and utilization in sheep fed opuntia (*Opuntia ficus-indica* (L.) Mill.) in combination with conventional green and dry fodders

**Introduction**

During summer the harsh agroclimatic condition in arid regions of the country, results in progressive denudation of surface vegetation leading to low energy availability and loss of production. However, the opuntia plant remains green even during summer and can serve as a feed resource during scarcity. In view of possible importance of opuntia as scarcity feed in hot semi-arid and arid environments, a study (Misra et al. 2018) was undertaken to assess nutrient intake and utilization in sheep fed opuntia in conjunction with conventional green and dry fodders.

The nutritive value of opuntia (*Opuntia ficus-indica* (L.) Mill.) in combination with conventional fodders was assessed on 32 adult sheep, divided into four equal groups. The experimental diets consisted of chopped (5-8 cm) green opuntia cladodes (150 g on dry matter basis per head daily) in combination with chopped green Napier (*Pennisetum purpureum*) grass (T1), berseem (*Trifolium alexandrinum*) hay (T2), lathyrus (*Lathyrus sativus*) straw (T3) and gram (*Cicer arietinum*) straw (T4) ad libitum. All experimental animals were supplemented with 200 g concentrate mixture per head daily.

**Salient findings**

Cactus pear was readily consumed and the animals ate everything offered to them. Total dry matter (DM) intake ranged from 3.39 to 4.35 per cent of live weight. The total tract apparent digestibility of DM, OM and CP were lower (P<0.01) in sheep fed cactus pear with gram straw (T4) diet compared to other diets (T1, T2 and T3). Intake of digestible DM, OM and total digestible nutrients (TDN) were significantly lower in T4 diet, where cactus pear was supplemented with gram straw as a basal feed, however, it did not differ
(P<0.01) with T1 diet. The digestible crude protein (DCP) intake was lower (P<0.01) in T4 (3.12 g/kg metabolic weight) when compared to the standard requirements of 5.00 g/kg metabolic weight in sheep for maintenance. But intake of TDN was over and above (48.74 to 62.10 g/kg metabolic weight) the prescribed requirements of 36.00 g/kg metabolic weight in sheep for maintenance when considered for all the groups. Animals of all the experimental groups were in positive nitrogen balance. However, N intake, balance, absorb and retention were lower (P<0.01) in T4 diet compared to other diets, but the N excretion through faeces and urine was similar in T1 and T4; and T2 and T3. No significant (P<0.01) changes in live weight were observed and animals maintained the live weight throughout the experimental period.

**Conclusion and way forward**

Cactus pear was highly palatable and in combination with conventional fodder sources could maintain adult sheep during summer in semi-arid conditions. Moreover, cactus pear may improve the nutritive value of poor-quality roughage due to its high content of soluble carbohydrates, but nutrient intake and utilization on cactus pear feeding with fodders having moderate level of protein appears to be more beneficial than the fodders which are lower in protein (12%). Animals maintained live weight without any digestive disturbances such as diarrhoea and bloating. The results may be used to derive practical rations for the animals in dry areas.

**1.3.3.3 Promoting Cactus as an alternative and sustainable livestock feed**

**Introduction**

Given the high water-use efficiency of cactus and its ability to withstand extremely dry conditions, cactus is increasingly being recognized as a more sustainable alternative to traditional livestock forage in dryland areas.

The work (Ben Salem and Louhaichi 2014; Rekik and Louhaichi 2014) illustrates the potential of cactus as alternative feed resource for dry areas. It also high lights salient points of the conducted in other parts of the world.

**Salient points**

The plant generates a high biomass of green forage – ranging from 30-250 t/ha in semi-arid areas, which is rich in carbohydrate, water and minerals but low in nitrogen. Cactus has a high soluble sugar content - over 60 g/kg dry matter, of which over 90% is represented by fructose, a sugar capable of significantly improving rumen fermentation. Cactus has the potential to significantly reduce the need for other high-energy feeds such as barley grains and maize – and unlike these crops, its excessive consumption will not cause acidosis in ruminants because of high levels of mucilage, which enhance salivation and avoid serious decreases in pH. The lambs fed on straw supplemented by cactus and Saltbush in Tunisia grew at a rate of 80 g per day. Also, incorporation of cactus cladodes into ruminant diets improves meat quality.
Nutrients are also required at mating time to enhance conception rates, thereby improving fertility and raising ovulation. Rams also respond positively to nutritional inputs by fully expressing their behaviour and producing higher quantity and quality of sperm. The conception rate of 18-month-old maiden ewes reached 90% when supplemented with 3.5 kg of cactus/head/day. In adult sheep, supplementing feed with spineless cactus pads prior to and during mating improved the number of large ovulatory follicles (+30%) and ovulation rates (+18%). At the end of a 90-day supplementation period, daily sperm output and testosterone secretion rates tended to be higher for cactus-supplemented rams.

Results from other countries are also highly encouraging. Dairy cattle in Brazil, receiving a complete mixed diet composed of 60% ground cactus cladodes, 20% chopped hay and 20% protein-rich concentrate, yielded around 25 litres of milk per day. South African lambs fed on a diet of sun-dried and coarsely-ground cactus cladodes mixed with Lucerne hay, yellow maize meal, sunflower olive cake meal, and molasses meal, grew at similar rates to those receiving a conventional diet – at a fraction of the cost. In Brazil, Morocco and Tunisia, farmers have preserved silage composed of cactus cladodes and other local ingredients through ensiling. The resulting feed has improved the milk production of dairy cattle and aided the growth development of goats and sheep.

Cactus plants are fragile and should not be grazed directly by animals, a practice that could drastically shorten the longevity of cactus plantations. Instead, cladodes should be harvested, cut into small pieces and distributed to animals - a ‘cut and carry’ methodology that is common in many cactus-cultivating countries, including Brazil, South Africa and Tunisia.

**Conclusion and way forward**

Given that cactus is low in fibre and nitrogen, its effectiveness as a livestock feed can only be fully realized if it is mixed with other feedstuff: fibrous material, such as hay or cereal straws, and sources of nitrogen such as shrubby legumes, cotton seed meal and sunflower meal. Conversely, cactus can be used to improve other unbalanced feeds. For example, the low energy and high salt content of Saltbush can be corrected by the high sugar and water content of cactus cladodes. Furthermore, cactus cladodes and cactus fruit have been incorporated successfully into feed blocks as a catalytic supplement for sheep and goats which were previously fed on low quality forage or allowed to graze already degraded rangelands. Cactus supplementation increased reproductive efficiency of sheep. Several examples available from other countries demonstrate high potential of cactus as an alternative feed.

For sustainable use of cactus as animal feed, the ‘cut and carry’ approach should be employed. The use of low-cost machines is designed to cut cactus rapidly and efficiently (as employed in Tunisia) and replaces time-consuming and labour demanding requirements of cutting cladodes by hand. If prices are beyond the means of low-income smallholder farmers, costs can also be shared amongst the farmers.

The high-energy, nutrient-rich cactus plant can reduce pressures on already-depleted natural resources and provide farmers with a guaranteed source of water during the dry season. It is suggested that countries invest in the establishment of shrub-like cacti plants to achieve sustainable animal food
sovereignty, divert funds from direct food compensation to scale up cacti cultivation and intensify research into suitable accessions. Additionally, extension programs should be encouraged to consider cacti as an integral part of feeding calendars and not just as rescue food during droughts.

1.3.4 CAPACITY DEVELOPMENT AND DISSEMINATION

Results from the study were disseminated to a range of stakeholders via a variety of mediums, including from farmers field days, on-job trainings, and group trainings, webinars, videos and TV shows, and the Zoom meeting.

1) Zoom meeting

Topics covered included using spineless cactus as an alternate fodder resource for drought prone areas, promoting cactus as drought resilient feed resource, cactus pear evaluation and best agronomic practices, capacity strengthening of different stakeholders, cactus pear crop management to increase productivity and enhance awareness about cactus cochineal.

These activities led to extensive use of cactus in arid and semi-arid regions of south and west Asia, the Middle East and North Africa.

1.3.5 CHANGING PERCEPTIONS AND ADOPTION

Studies were also carried out to assess the adoption of the cactus utilization.

1.3.5.1 Adoption and Utilization of Cactus Pear in South Asia—Smallholder Farmers’ Perceptions

Introduction

Livestock production in arid and semi-arid regions is facing the challenges of low and erratic rainfall, poor nutrient soils and high temperatures, which all contribute to inadequate forage production to support livestock. Under these challenging conditions, promoting forage species, such as cacti, that are tolerant and well adapted is important to sustain and improve livestock production.

A study (Louhaichi et al. 2018a) was conducted to analyse the potential of adopting a spineless cactus through analysis of smallholder farmers’ perceptions with respect to its potential use as a livestock feed in three states in India (Rajasthan, Gujarat and Uttar Pradesh) and in Punjab, the largest province in Pakistan. A total of 456 households were stratified into three groups in 2017: Farmers not familiar with cactus (non-adopters), farmers familiar with cactus but not growing it (potential adopters) and those already growing it (actual adopters).

Salient findings

In Pakistan (74%) indicated that cactus is a cheaper source of livestock feed and they would highly recommend it to their neighbours. In India, a high proportion (84%) of farmers were satisfied with
spineless cactus as a cheaper source of alternative livestock feed, and 78% of them mentioned that it is an ideal livestock feed. The study confirmed that farmers already growing cactus are satisfied with its potential. A considerable proportion of non-adopter farmers cited the unavailability of plant material and technical information as the main reason for their lack of interest in cultivating spineless cactus. There was some negative opinions and attitudes toward cactus, and a lack of technical information concerning its cultivation and processing.

**Conclusion and way forward**

A considerable proportion of farmers in both countries accept that cactus pear has a role in providing a source of livestock feed and contributing toward reducing rangeland degradation. However, there is still a need to educate local farmers on the socioeconomic and environmental values of this very useful and widely found plant. Moreover, for sustainable intensification of livestock production in degraded ecosystems, an approach that aims at reducing the use of human-edible food resources and increasing that of by-products from sustainably managed rangelands should be emphasised. Such an approach is critical for coping with the increasing global demand for food against the background of the limited available area of cultivable land to produce grain crops. Therefore, engaging smallholder farmers through extension and research organizations is pivotal, to transfer research information, raise their awareness about the spineless cactus and its benefits.

The technology of feeding livestock with spineless cacti is relatively new in both countries, and research, in the long-term, should also focus on establishing the preferences and disparities of women and men in terms of opinion and adoption concerning introduced agricultural technologies, such as cactus cultivation. The practical field trials demonstrating the benefits of the spineless cactus as a feed source are useful for the prioritization and implementation of its use during low forage periods such as the dry seasons.

The potential gains of livestock farming from spineless cactus production in the world’s dry areas could be immense. Although more efforts, through farmer education and information sharing, are needed to ensure that the plant’s potential is effectively realized.

**1.3.5.2 Changing the perception of smallholder farmers about cactus pear in Pakistan**

**Introduction**

The increasing demands of water and feed resources across the world’s dry areas require alternative sources of animal feed – specifically crops with better water-use efficiency. One alternative with the potential for widespread contribution toward reducing the impact of reduced feed and water availability is the cactus pear (*Opuntia ficus-indica*). Several efforts have been made to promote cactus pear as a feed resource for livestock, as it is a drought-resistant succulent plant that is spineless and holds a large amount of water.
A study (Louhaichi et al. 2019b) was conducted to examine the adoption of cactus in Pakistan, through targeting 100 households selected from three strata groups: farmers not familiar with cactus, farmers familiar with cactus and farmers who had already adopted cactus.

Salient findings

There is a general acceptance of cactus by farmers, although they stated the lack of available technical or financial means as a reason for their lack of interest in cultivating cactus. The survey also showed that many smallholder farmers are familiar with cactus and are also convinced that it can be adopted for livestock feeding.

Conclusion and way forward

Cactus has huge potential in Pakistan as a non-conventional and valuable fodder for resource-challenged areas, especially because farmers have very positive attitudes toward cactus adoption. However, more efforts are still needed to provide the appropriate technical information to ensure that the plant’s potential is effectively realized. This can be achieved through the active role of local institutions, NGO’s and farmers’ associations.

1.3.5.3 Cactus: catching up in India

Introduction
Smallholder farmers in semi-arid environments have limited resources to improve the supply of animal feeds. Cactus pear (*Opuntia ficus-indica*) shows great adaptive traits under harsh agroclimatic conditions and often thrives where no other crops can grow. Cactus as a fodder crop can address the widespread shortage of green fodder. ICARDA jointly with Indian Council of Agricultural Research (ICAR), Indian Grassland and Fodder Research Institute (IGFRA) and ICARDA-FAO Cactus Net explored (Louhaichi et al. 2020) the potential of using cactus pear as a new source of fodder.

![Cactus pear mixed crop field at the Indian Grassland and Fodder Research Institute in Uttar Pradesh, India. Photo ICARDA](image)

**Salient findings**

The work (Louhaichi et al. 2018b) identified: a) cactus accessions adapted across several agroecological production systems, b) developed the best agronomic practices for optimum spineless cactus growth to increase yield and quality under different environments, c) developed various cactus-based feed rations depending on available feed resources, and d) enhanced capacity building of all partners, while also disseminating the projects findings to other areas of India. More than 120,000 cladodes were distributed and planted in 1200 farmers’ fields. The best planting time in India is July before the monsoon. Well-adapted cactus pear accessions have been identified. Demand for cactus cladodes is expanding as more states request this crop.

A cactus suitability map in India was generated (Acharya et al. 2019). About 32% of the total geographic area of the country is in the high to moderate suitable category, and 46% falls under the marginally suitable and 22% under the low to very low suitable category. The suitability analysis, based on the precipitation anomaly (2008–2017), suggests a high probability of cactus growth in the western and east-
central part of India. The relationship with aridity index shows a decreasing rate of suitability with the increase of aridity in the western and east-central provinces ($\beta \sim -1$ to $-2$).

**Conclusion and way forward**

Cactus pear has the potential to: 1) help farmers cope with climate change and variability, 2) grow on marginal land with little input, 3) increase water use efficiency of production systems, 4) solve the problem of increased demand for green fodder and 5) reduce livestock watering.

Integrating cactus into dryland farming systems and rangelands under changing climate can be one plausible solution to build resilient agroecosystems that provide food and fodder while enhancing the availability of ecosystem services.

Future actions involve supporting local institutions, NGO’s and farmers’ associations to play an active extension role; setting up nurseries across several states to speed up cactus pad multiplication; developing the capacities of farmers, extension services, local authorities and development agencies on cactus production; and exploring additional uses of cactus such as fruit production.

### 1.3.6 RANGELAND REHABILITATION AND ECOSYSTEM GOODS AND SERVICES

In dry areas, rangeland degradation and loss are extensive. The factors responsible include expansion of cultivated land, illicit wood collection, overgrazing contributing toward erosion, frequent droughts, inappropriate development of policies and regulations around resource utilization, and climate change. Cactus cultivation provides several ecosystem goods and services including rehabilitation of rangelands.

#### 1.3.6.1 Cactus (*Opuntia ficus-indica*) utilization for rehabilitating rangelands in arid regions of Tunisia

**Introduction**

Currently, rangelands contribute 10-25% of livestock feed requirements, compared to 65% in the 1960s, reflecting important rangeland degradation and loss. Direct factors responsible for the loss/degradation of rangelands include expansion of cultivated land, illicit wood collection, overgrazing contributing toward erosion, frequent droughts, inappropriate development of policies and regulations around resource utilization, and climate change. Considering this, a national strategy for rangeland rehabilitation was launched by the Tunisian Ministry of Agriculture in 1990, and the strategy included cultivating Atriplex, Acacia and spineless cactus (*Opuntia ficus-indica*) shrubs on a large scale. This strategy was implemented by the OEP focusing on private rangelands, with a contract established between OEP and farmers. The OEP provided the cactus pads and the equivalent of US$70 per ha as an incentive to cover costs related to planting. In addition, the OEP provides technical assistance to farmers (Gouhis et al. 2019).

**Salient findings**
So far, the non-planted areas have produced 0.2-0.5 t DM per ha as feed, while the feed biomass increased to 6-12 t DM per ha in the cactus planted areas. Other benefits of cactus plantation included increased fruit production for self-consumption or sale, reduction of soil erosion, improvement of biodiversity, shelter for wildlife and improved carbon sequestration.

Conclusion and way forward

Land cover, feed and water resources are low on Tunisian rangelands and other such dry areas. The cultivation of cactus presents an opportunity to restore degraded areas. Simultaneously, livestock production stands to benefit, as cactus is also an important feed resource during barren and dry periods.

1.3.6.2 Cactus: provision of ecosystem goods, services and function

Introduction

Half of the world’s livestock and 44% of the world’s food is produced in dry areas. The productivity in these areas can be increased by the cultivation of adapted crops that can thrive in these conditions. Spineless cactus pear (*Opuntia ficus-indica*) is an ideal candidate that can grow in the driest and most degraded land. Cactus is a multipurpose crop with significant ecological, economic and social potential. However, this crop continues to receive limited scientific, political and media attention.

The main objective of this study (Louhaichi et al. 2018c) was to highlight the benefits and ecosystem services generated from cactus pear.

Salient findings

Cactus can play significant roles in the livelihood of smallholder farmers. It can be used as fruits for human consumption (8 metric tons of fruit production at 2,000 plant per ha), as a vegetable crop (80-90 t/ha at 40,000 plants per ha) and as fodder for livestock (25 t/ha per year). It is the source of wide range of medical products and by-products such as seed oil, cosmetic, industries and processed fruits. Cactus pear can be used for soil and water erosion control, regulation of climate through carbon sequestration and biodiversity conservation. Cacti are also capable of taking up relatively large amounts of CO2 with respect to water loss by transpiration (4 to 10 mmol CO2 per mmol H2O, compared to 1 to 1.5 mmol in C3 plants).

Conclusion and way forward

A major shift in the role of cactus pear is necessary, which aims at balancing environmental conservation, farming systems with socio-economic development. Promoting the ecological, economic and social benefits of cacti and strengthening the technical capacity of human resources will benefit the fodder availability and by-products from cactus production.

1.3.7 OVERALL CONCLUSION, LESSONS LEARNT AND WAY FORWARD
The ICARDA program on cactus has conducted research and development work that covered a wide spectrum of issues: assessment of the adaptability of different cactus pear accessions across a range of agroecological zones; good management practices for cultivation and management of cactus in dry areas to maximise the productivity of cladodes and fruits; use of cactus as a fodder in dry areas including the Middle East, North Africa and south Asia; management of rangelands using cactus; ecosystem goods and services; and providing livelihood opportunities for farmers and nutrition for people and livestock in dryland areas. In partnership with the national agricultural research systems (NARS), the work included awareness-building and capacity-development through field days, social media campaigns and the production of a special documentary broadcast on national TV, with the aim to change farmers’ perceptions, attitudes and practices around cactus pear, while showing them the advantages of the plant as fodder reserve for livestock.

Cactus pear is now a highly promising crop across dry areas in the Middle East, North Africa and in India. In some locations, it has replaced up to 35% of less hardy, unreliable green fodder especially during drier periods, resulting in 30% extra milk yields from livestock. Several cactus pear nurseries have been launched across India and Jordan, and an awareness outreach program has been established to inform decision makers, government officials and farmers beyond the CGIAR sphere of influence about the crop’s importance. Studies with farmers in India and Pakistan indicate that 90% of responders are eager to begin growing the plant. Against the backdrop of ongoing climate change, prolonged droughts, land degradation and desertification, this hardy crop demonstrates significant social, environmental and socio-economic benefits, including soil and water erosion control, regulation of climate through carbon sequestration, biodiversity conservation and habitat for wildlife. There is increasing global interest and uptake, especially under expected ongoing climate change, prolonged droughts, land degradation and desertification, particularly in dry and arid areas.

From their native distribution area in Mexico, the Opuntia species have spread throughout arid zones around the world, particularly in the Mediterranean basin, northern and southern Africa, the Middle East, Australia and northern India. The reasons behind the diffusion of Opuntia species around the world and particularly the species *O. ficus indica*, are numerous, they include:

1) the simple cultivation practices required to grow the crop
2) its quick establishment soon after the introduction in a new area
3) the easy multiplication practices that favour rapid diffusion and exchange of material among users
4) the ability to grow in very harsh conditions characterized by high temperature, lack of water and poor soil
5) the generation of income from the selling of much valued and appreciated fruits
6) the use of its stems in the human diet and as fodder for the livestock
7) the useful deployment of its plants for fencing farms
8) the nutritional value of its juicy fruits
9) the long shelf-life of the fruits
10) the many industrial derivatives produced from the fruits
These attributes have largely contributed to such a wide distribution from its original areas in Latin America to remote areas across continents and across cultures and traditions. After their introduction in new areas, cactus pear plantations have gained an important place in the agricultural systems as fruit, forage and fodder provider, particularly in subsistence agriculture where they have a comparative advantage for their capacity to grow with minimal agronomic inputs, for their resistance to drought, etc. In these countries, the cactus pear underwent processes of adaptation and selection that eventually led to new ecotypes and varieties, adapted to specific local habitats.

FAO-ICARDA CactusNet, an International Technical Cooperation Network on Cactus Pear, has been established in partnership with FAO. Through the network, ICARDA facilitates business development ‘entrepreneurship’ by sharing experiences from all over the world in all aspects of cactus use, including for medicinal and food purposes. Through the CactusNet, ICARDA jointly with FAO and other partners published an exhaustive book (Inglese et al. 2017) covering a wide range of subjects, from fundamental areas such as history, economic and agro-ecological importance, origin and taxonomy of *Opuntia ficus-indica*, exploitation of cactus for fruit and vegetable production for human consumption to forage production for animal nutrition. This book has become a useful resource for countries interested in developing or increasing cactus production.

A Google Earth Engine (GEE) map has also been developed and trialled by researchers to show suitable areas for cultivation of the plant across India, a technology that can now be applied to any country and crop. A safer, more practical and more cost-effective cactus pear chopper has also been designed to speed up harvesting and ease incorporation of cactus pear into livestock diets. A manual on cactus agronomic practices developed for dry areas in India is expected to benefit farmers and development workers interested in cactus cultivation in other arid and semi-arid regions of the world.

Within the collaboration program between NARC and ICARDA, more than 100 accessions of cactus pear were introduced and planted in Muchaqqer research station, Jordan. Fifty fruiting type cactus pear accessions were selected to be distributed to the farmers and these accessions showed good performance. Cactus pear accessions present an opportunity to help farmers in Jordan to diversify their products and increase their income because the market for cactus fruits is very promising. The diversity of these accessions created the interest of many farmers to start growing cactus pear. The cactus germplasm collection at Mushaqqr research station has been playing an important role towards the high adoption rate of cactus pear by the farmers (Louhaichi et al. 2020). It is considered as a successful collaboration program between NARC and ICARDA. However, there is a need to ensure that this germplasm is well maintained and with no risk of being contaminated by the Cochineal, which is already found in the northern part of Jordan.

Evaluation of data collected from this gene bank will be used by various researchers involved in cactus pear around the Middle East and other parts of the world. In addition, plant material of described accessions from these germplasm blocks will be used to establish additional germplasm blocks in other provinces, to monitor the performance of various accessions in the different agroecological regions of
world. It is therefore recommended that the accessions be evaluated on a yearly basis to obtain long term data that will assist in future decision making. More research is needed to assess factors affecting the plant quality characteristics.
1.4. HIGH-QUALITY CASSAVA PEEL MASH AS A FEED INGREDIENT

This section presents work conducted on development and use of a novel feed resource, cassava peel mash, which was produced from cassava peels. The work on development of this novel feed was led by ILRI with support from IITA and the Roots, Tubers and Bananas CRP as well as the Livestock CRP.

Globally, livestock production has been adversely affected by the effects of climate change, especially impact on the availability and quality of feed resources, particularly during the dry season. In addition, the conventional feed resources such as maize and soybean are getting expensive due to their increasing demand globally. Opportunities exist to evaluate a range of new and novel feed ingredients for use in poultry and livestock rations.

The International Livestock Research Institute (ILRI) has developed innovative methods of processing cassava peels into feed products, namely High-Quality Cassava Peel mash, patented as HQCP®. These methods involve a combination of different physical processes such as grating, dewatering, pulverizing, and sun-drying or drying by toasting on a fire-heated pan or flash dryer in the case of a commercial producer (Amole et al. 2019). Investigations on nutrient composition of the HQCP® mash and its inclusion at varying levels into poultry, aquaculture and ruminant diets have been conducted, all aimed at understanding the level at which the inclusion of HQCP® mash will support the best performance while examining the economic implications of the inclusion of this ingredient.

**Salient findings**

Crude protein of the mash was not very high, largely varied from 2.3-3%, while it was rich in starch (72-83%), an energy source. Aflatoxin was not detected and another antinutritional factor, hydrocyanic acid was < 2.76 mg/100 g, which is lower than the permissible level of 10 mg/100 g. The high energy content in the HQCP® mash suggested that it could be a good alternative to energy-rich conventional feed resources such as maize or wheat in the diets of animals, poultry and aqua species.
The HQCP® mash was evaluated as a part of the diets of pigs, poultry, sheep and fish.

**Pig.** The HQCP® fine mash can be used to replace up to 75% of the maize in the diet of growing pigs (maize level in the diet 40%) without any adverse effect on the growth performance and blood biochemical indices. A cost-benefit analysis showed that the inclusion of the HQCP® mash at up to 15% of the diet (37.5% replacement of maize) was most beneficial. This level of incorporation is also suggested for the weaner pigs (Adebiyi et al. 2017).

![Step-by-step process to produce High Quality Cassava Peel (HQCP) mash. Photo extracted from 'Transforming cassava peels into animal feed' video https://www.youtube.com/watch?v=jkvHYqPLvyc](https://www.youtube.com/watch?v=jkvHYqPLvyc)

**Poultry (broiler).** The diets containing 29-48% replacement of maize with the HQCP® fine mash recorded the highest body weight and live weight gain (maize in the diet 52%). The feed conversion ratio (FCR) was highest in the birds fed a diet containing 29 % replacement of maize (15 % of the HQCP® fine mash in the diet), and this level of incorporation reduced the cost of feeding and improved the production performance of the birds the most. Furthermore, the replacement of up to 60% dietary maize with the HQCP® fine mash did not affect the carcass yield, except for breast meat yield, which decreased by 25% (Adekeye et al. 2021).

**Sheep.** The inclusion of the HQCP® fine mash at up to 50% in a diet supplemental with urea increased body weight gain and reduced the unit cost of feeding by nearly 40%, giving higher profit from fattening of ram (Amole 2019, Unpublished). In another study, feeding of rams with the HQCP® fine mash as a sole diet offered *ad libitum* or supplemented with dried *Ficus thonningii* foliage at 20%, 40% and 60 % concluded that the foliage supplementation up to 60% improved total dry matter intake, nutrient digestibility and body weight gain (Bakare et al. 2019).
Fish. The use of the HQCP® fine mash as a replacement of maize in the diet of juvenile African sharptooth catfish (Clarias gariepinus) for a period of 84 days showed that the mash can completely replace maize in the diet of catfish, decreasing the cost of feeding (Premium Feeds, 2018).

**Constraints in the use of the HQCP® mash.** Constraints include: the low selling price of the HQCP® mash, because of lack of awareness of the quality of the mash among the users; low production capacity of the producers and as a result low and inconsistent availability of the mash, which lowers feed millers’ interest in this novel feed; production of unstandardized HQCP® (Amole interpersonal communication) products of varying quality; varying price; high cost of the machines; difficulty in drying during raining season and the fear of high level of cyanide. These have so far limited the commercialization and scaling-up of this technology but the use of HQCP® is growing year on year.

![Weighing grated peels before processing them. Photo ILRI/Tunde Amole](image)

**1.4.1 CONCLUSION, LESSONS LEARNT AND WAY FORWARD**

The HQCP® mash can replace a substantial amount of maize in the diets of pig, poultry, sheep and catfish without sacrificing their production and productivity. The use of the mash decreases the cost of feed. Its use has the potential to decrease food-feed competition and pollution associated with irresponsible disposal of cassava peels. A concerted effort is needed to make the HQCP® mash a mainstream feed resource by overcoming constraints identified in the above-stated study. The multi-stakeholder scaling study aimed at increasing transformation of fresh cassava peels to the HQCP® mash not only in Nigeria but also in Ghana, Democratic Republic of Congo, Rwanda and Tanzania, under one CGIAR programme, would increase income of the farmers as well as entrepreneurs, create employment, and mitigate feed scarcity and environmental pollution. Potential of the mash as feed for laying hen, dairy animals and other aqua species should also be investigated.
To recap, this section has highlighted the role of cactus as a feed for the dry areas and for sustainable management of the degraded lands. It has been widely adopted in North Africa, west Asia and the Middle East. The HQCP® mash from cassava peels is a good energy source and can replace conventional energy-rich feeds such as maize in the diets of livestock and aqua species. The technology to produce mash has the potential to generate employment. Currently, this technology is in infancy in terms of its application. More work is required on scaling-up and scaling-out of this technology.
EFFICIENT USE OF FEED RESOURCES

The sustainability of the livestock production system hinges on how feed is produced and fed to livestock. Feed production is resource hungry in terms of land, water, energy, labour, seeds, planting material, fertilizer and pesticides. Efficient use of feed resources leads to a ‘win-win’ situation both for the livestock industry and the environment – it increases profit by increasing livestock productivity and decreases water and carbon footprints by decreasing use of natural resources.

The research conducted on efficient use of feed resources is synthesised in this section. Initially, a prototype that assesses feed availability and feed requirement, and from these two entities estimates feed balance is presented. This is followed by strategies that enhance nutrient availability from basal diets. Next is the presentation on balancing of diets, which is the fundamental principle of sustainable livestock production. The diets must meet nutrients required by the animal to meet the production target for which it is being reared. The penultimate section deals with the sustainable management of crop and grassland resources, and finally the work conducted in India and Tanzania on feed and feeding intervention is discussed.
2.1 FEED BASE-ETHIOPIA: A PROTOTYPE DATABASE AND DECISION-MAKING TOOL FOR ESTIMATING SUPPLY AND DEMAND OF LIVESTOCK FEED RESOURCES IN ETHIOPIA

Most developing countries do not have quantitative information on availability of feed resources. It is impossible to effectively manage a resource if its availability is not known – the same holds good for feed resources. While feed base or feed assessment provides critical information on feed productive capacities and feed availability, the sufficiency of the feed supply can only be gauged relative to demands for feeds. Essentially, this comparison between livestock requirements and feed supplies constitutes the feed balance. In many countries feed balances are not usually available or accurate despite their strategic role for livestock development opportunities, for providing input data into country level food input-output analyses and for emergency alerts and monitoring. A prototype has been developed, taking Ethiopia as the case country, to assess feed availability and feed balance.

Introduction

Despite various reports on available feed resources in Ethiopia, there has been limited effort to properly estimate feed balance. There is an apparent mismatch between available feed resources and livestock numbers, aggravated by rainfall seasonality, droughts and deterioration of communal grazing lands. However, the extent of this shortfall and its geographic variation are not well understood. Knowledge of the supply and demand of feed resources is a vital component in feed resource management, investment in feed business and informed decision making.

The National Institute of Animal Nutrition and Physiology (NIANP) in Bangalore, India, developed ‘FeedBase-India’, a methodology for assessment of the availability and requirement of animal feed resources in India. Realizing its importance, the Ministry of Agriculture, Ethiopian Agricultural Transformation Agency (ATA), Indian Council of Agricultural Research and ILRI initiated a collaboration to contextualize and adopt the tool to estimate the Ethiopian feed supply-demand ratio (Angadi et al. 2021) and to turn the database into a decision-making tool with interactive features that would enable users to compare and prioritize feed and animal interventions for impact.

Preliminary feed supply and demand estimates were established for 63 districts (woredas) across the Amhara, Oromia and Tigray regions of Ethiopia. Feed supply was estimated from cropping and land use patterns based on crop yields and crop specific conversion factors such as harvest indices and brans after grain processing and cakes after oil extraction. Feed biomass yields from planted forages, common property resources, rangelands, road-side grasses and forests were calculated based on region-specific research data.

Feed demand was calculated from livestock numbers, livestock species and herd structure. Minimum essential feed demand was calculated based on specific energy requirements of a livestock species for maintenance and production for each district. Feed quality was estimated based on ILRI and Ethiopian
Institute of Agricultural Research (EIAR) feed libraries (Angadi et al. 2021). Data on all individual feed resources, their quantity and quality, livestock species, number and herd structures were organized in a pilot tool leading to a balance sheet where feed surplus or deficit was calculated and displayed in a flexible manner.

**Salient findings**

The feed base tool, originally developed for India, has been adapted to estimate feed balance for Ethiopia using data collected from 63 districts. The analysis indicated a metabolizable energy deficit of 42% in relation to demand, which warrants investment in improving the feed value chain.

Only six districts (Ofla and Atsbi Womberta from Tigray; Teltele from Oromia; and Kalu, Farta and Denbiya from Amhara) show a feed surplus in that more feed metabolizable energy was calculated as being available than required. The result is comparable those in the FAO (FAO 2018) report which maps feed resource availability and feed balance at a broader scale (regional level). According to FAO, the total annual potential biomass available for animal feeding in Ethiopia is 144.48 million tons with feed deficits of 9% for dry matter, 45% metabolizable energy and 42% crude protein in all regions except Benishangul-Gumuz and Gambela.

The reliability of evidence from the tool depends on the quality of data used as an input such as livestock census, crop production and land use. Agricultural data from the Central Statistical Agency uses zone as a measurement unit, while the feed base tool uses district-based data. Thus, adjusting the data collection system or designing a separate data collection system for the feed base tool will improve the quality of information generated.

Improving official data collection systems would greatly improve the strength of the tool as a decision support mechanism for the Ministry of Agriculture and other decision makers.

**Conclusion, lessons learnt and way forward**

The feed base tool shows strong potential for use in decision support, provided the necessary data is collected at the district level. The use of tool would help strengthen the feed related data, which is a prerequisite for sustainable development of the livestock sector.

Both the piloting exercise and the recent study by FAO showed a significant gap in feed availability. To ensure continuous supply of feed and improved livestock productivity, the feed sector must be commercialized by supporting smallholder farmers and private investment in the feed value chain. A functional feed base tool would support this process.

In the current prototype, livestock census data collected by the Central Statistical Agency (CSA) is the zonal data which is not appropriate for the Feed Base tool to make calculations of feed balance. Thus, modifying the CSA measurement unit from zone to district, or designing a district-based data collection system
within the Ministry of Agriculture would provide an opportunity for improvement and scaling up. In this regard high-level discussions between the Ministry and CSA would be important.

Feed and forage production are not currently considered as enterprises that require strong value chain development. Success in the livestock sector cannot be realized without having a vibrant, sustainable and strong feed value chain and developing tools such as the feed base tool could help to support decision making for investors.

Knowledge of the feed balance will help policy makers to proactively identify available feed resources to overcome feed shortages during emergency periods such as drought. The tool provides opportunities for policy makers, researchers, development agencies, government, industry and farmers in better planning and decision making in the livestock sector. It would help developing climate-smart feed production and feeding strategies, resulting in higher livestock production and productivity, reduced feeding cost, increased feed use efficiency and reduced greenhouse gas emission.

The tool could also be further developed for assessing the environmental footprint of feed production by quantifying water requirements and carbon emissions associated with the choice of feed resources and feeding interventions.

The conceptual framework used in the tool can be applied to assess feed balance in other countries. Work on these lines is in progress in Nigeria.
2.2 ENHANCING AVAILABILITY OF NUTRIENTS FROM THE BASAL DIET

Crop residues and poor-quality grasses are the main basal diet for livestock production in developing countries. They form 50-70% of the livestock feeding basket in these parts of the world. Crop residues are low in nutritional quality (deficient in nitrogen, vitamins and minerals) as well as low in digestibility due high levels of rumen microbe-inaccessible-macromolecules present in them. A combination of low content of nutrients and low digestibility makes them poor feeds for the livestock. Several chemical and biological approaches have been applied that breaks and/or loosens the complex macromolecular structure present in the crop residues, enhancing accessibility to rumen microbes and as a result increasing availability of nutrients for livestock production. Some such treatments also increase crude protein content of the basal diet. Another approach to enhance availability of nutrients from the basal diets is their supplementation with other feed resources that provides the nutrients deficient in the basal diets. The supplementation approaches enhance rumen microbial activities, which in turn enhance degradation of the diet, including the basal diet, enhancing availability of nutrients from the basal diets for animals which otherwise were unavailable in absence of supplementation. This section presents both these approaches.

2.2.1 BASAL DIET IMPROVEMENT

2.2.1.1 Turning cereal straws and stovers into concentrate feeds through leveraging on second generation biofuel technologies – case of India

Introduction
Crop residues such as straws, stovers and haulms contribute more than 70% of the animal feed basket in India based on mass. But they are poor in quality and a significant improvement of their nutritional value could lead to high livestock production and productivity in India and other developing countries. One of the reasons for the poor quality of the crop residues is the complex bonding between cellulose, hemicellulose and lignin in them, which the rumen microbes cannot break completely. The second-generation biofuel technologies have gained wider acceptance because they produce sugar for conversion into ethanol from crop residues which do not compete with human food, unlike first generation biofuels that convert grains and other foods to ethanol. Feeding of the intermediates, obtained by loosening of macro-structure and digestion of the macro-molecules of crop residues by chemical and enzymatic approaches used in the production of second-generation biofuels, could yield higher energy to the animals, resulting in higher animal production and productivity.

ILRI and its partners (Nagarjuna Fertilizer and Chemical Research and Development, India; Michigan Biotechnology Institute (MBI); Indian Institute for Chemical Technology (IICT) and a CSIR institute, India) evaluated the effects of three following mentioned second-generation biofuel technologies on the feeding quality of crop residues (Blümmel. 2019).

1. Steam explosion: Maize stover and sorghum stovers were steam-treated using intermittent live steam injection to heat stovers to 160°C for 10 minutes.
2. Ammonia Fibre Expansion (AFEX): In this treatment, ammonia vapor is added to the biomass under moderate pressure (100 to 400 psi) and temperature (70 to 200°C) before rapidly releasing the pressure and recovering more than 95% of the ammonia used in the process. Several serial straws were evaluated.
3. Chemical treatments: Two chemical combination treatments developed by IICT and CSIR were used to treat several stovers and straws.

Salient findings

Among the three treatments, the two chemical combination treatment (2-CCT) developed by IICT and CSIR was most effective, followed by the ammonia treatment and the steam treatment. The 2-CCT on average increased the true in vitro organic matter digestibility (IVOMD) by 38.2% units, from 55.9% in untreated straws and stovers to 94.1% after treatment. Likewise, the 2-CCT produced the greatest effect on livestock productivity. A total mixed ration containing the treated rice straw promoted an accumulated live weight gain (LWG) 7.85 kg — 3.7 times that produced by the total mixed ration containing untreated rice straw. The steam treatment had a high positive effect on voluntary feed intake (5.3% of body weight) and promoted live weight gain of 6.28 kg.

Conclusion and way forward

Increases in IVOMD and LWG were substantial, and the 2-CCT converted straws and stovers, in essence, into concentrate-quality feeds. Steam treatment should also be further explored together with the 2-CCT. An economic analysis that assesses the costs involved in the treatment and comparison of the cost per
nutrient of the treated products with those of the conventional feed resources, particularly high in energy is needed.

2.2.1.2 Improving the nutritive value of cereal and pulse straws using dung ash and wood ash treatments

Introduction

Cereal and pulse crop straws are important feeds for ruminants in mixed crop-livestock systems in Asia and Africa. Several alkaline treatments such as sodium hydroxide, calcium hydroxide and potassium hydroxide have been reported to improve the nutritive value of straw, but the practical use of these treatments is still restricted due to safety concerns, cost, environmental hazards and potential negative consequences on the health of the animals consuming the treated straw. Ashes, produced in considerable quantities by households in rural areas which use wood and dung as domestic energy source, can be cost-effective alternatives to traditional alkaline solutions for straw treatment.

A study (Alkhtib et al. 2019b) was conducted to evaluate the effect of treatment of straws with cow dung ash treatment and wood ash on their nutritive value. Accordingly, straws of barley, wheat, chickpea, faba bean and lentil were treated with dung ash at levels of 0, 100, 200 or 300 g dung ash/L and wood ash at levels of 0, 100, 150 or 200 wood ash/L.

Salient findings

The effect of dung and wood ash treatment depended on the origin of straw (P<0.001). Soaking straw in plain water did not alter IVOMD regardless of the origin. Dung ash treatment at the level of 300 g ash/L improved significantly IVOMD of barley straw. Ash treatment at 200 g/L and 300 g/L levels significantly (P<0.001) decreased the IVOMD of faba bean straw. Soaking straws of chickpea and faba bean in wood ash solutions decreased IVOMD significantly. Treating lentil straw by a solution containing 200 g wood ash/L decreased significantly IVOMD. Wood ash treatment did not alter IVOMD of straws of barley and wheat.

Conclusion and way forward

Treating barley, wheat, chickpea, faba bean and lentil straws by a solution prepared from dung- and wood-ash at a concentration up to 300 g dung ash/L and 200 g wood ash/ L failed to increase the nutritive value. Improving the effectiveness of dung- and wood- ash in solutions for enhancing the nutritive value of straws should be studied further by combining the ash solutions with other alkalis.

2.2.2 SUPPLEMENTATION TO ENHANCE NUTRIENT AVAILABILITY FROM BASAL DIETS

Individual studies have been presented in the section ‘Cultivated forages and their impact in Ethiopia’. These studies aimed to determine the effect of supplementing increasing levels of dried tagasaste leaf on the nutrition and performance of sheep fed a basal diet of barley straw; evaluate the effect of replacing a
concentrate supplement with an oat-vetch mixed forage on the performance of lambs fed Desho grass basal feed *ad libitum*; and evaluate replacement value of cowpea forage for a concentrate mix on performance of sheep fed a basal diet of Napier grass. All these supplementation studies enhanced livestock production and productivity. Likewise, supplementation studies mentioned in the section ‘multi-dimensional improvement of food-feed crops’, in which the genetically improved straws were supplemented with nitrogenous feeds enhanced livestock production and productivity.

### 2.2.3 OVERALL CONCLUSION, LESSONS LEARNT AND WAY FORWARD

The two chemical combination treatment shows the potential to convert straws and stovers into high quality feed resources, but currently the technology is not mature enough to apply on a large scale. An economic analysis that assesses the costs involved in the treatment and compares the cost per nutrient (CP and metabolizable energy) of the treated products with those of the conventional feed resources is needed. Equally important would be to assess the feasibility of large-scale application of this process. Leveraging the developments in the second-generation biofuel technologies is an interesting option to follow by animal scientists.

Dung ash as a source of alkali to loosen the complex macro-structure in straws of pulses and cereal was not found to be effective. It would be worth exploring the effect of ash from another source or combination of dung ash and other low-cost alkali. The results presented in section on ‘multi-dimensional improvement of food-feed crops’ show that the urea treatment of straws of lentil, chickpea and field bean has been effective in enhancing their digestibility and nutritive value. Although it is argued that the urea treatment is skill- and resource-demanding, while the genetic improvement of straws provides ‘permanent’ benefits, the former may be considered on case-by-case basis, as and when appropriate. It can provide benefits if applied as a business model. Urea treatment has not been adopted by smallholders but when applied in large-scale settings, for example by cooperatives, farmers group or an entrepreneur, it can provide benefits to livestock farmers including smallholders (FAO. 2011). Urea treatment of genetically improved straws might further increase their digestibility and nutrient availability from them to the livestock, provided it is economically viable.

The studies mentioned in section ‘Cultivated forages and their use in Ethiopia’ has illustrated the benefits of supplementing barley straw, Desho grass and Napier grass with tagasaste, oat and vetch mixed forage and cowpea hay respectively. Use of supplementation strategies that provide nutrients deficient in crop residues and poor-quality grasses, is a proven approach for enhancing nutrient availability from them and for enhancing livestock production and productivity. This approach is a backbone for the preparation and feeding of the balanced rations, as illustrated by the digital tool for balancing diets developed and used in India, through this project.
2.3 BALANCING DIETS

2.3.1 A digital advisory tool to reduce yield gap in dairy animals

Introduction

The productivity of livestock in Asia is far below the global benchmark, which is largely attributed to the poor quality and low availability of feeds. In addition, there is inefficient utilization of the available feed resources. In the mixed farming system, generally farmers feed their livestock with whatever is available on their farm, in the form of crop residues alone or supplemented with home-grown or purchased forages and concentrates. The farmers lack knowledge on the nutritive value of these feed resources, nutrient requirements of the animals and formation of the balanced diets. This leads to feeding of unbalanced diets, resulting in low animal production, high environment pollution and high milk production cost.

A digital advisory tool was developed by ILRI to address the mismatch between nutrient requirement and nutrient availability in dairy animals in the mixed crop-livestock system (Padmakumar et al. 2021). The tool ‘On-farm Feed Advisor’ is a mobile phone based nutrient balancing application downable from Google Play Store (https://play.google.com/store/apps/details?id=org.ilri.ilrifeedadvisor) and Apple Store (https://apps.apple.com/in/app/on-farm-feed-advisor/id1570480676). It can be operated by extension workers, progressive farmers and farm managers with a basic understanding of animal nutrition. The tool is currently applicable only for dairy animals.

The output from the tool, as least cost ration formulation advice, can be converted into a pdf document and shared through electronic media including smartphones. The output is at the individual cow level. The tool also helps to conduct centralised analysis to understand the general nutritional status of animals in a locality and to propose common feed related recommendations.
Salient findings

The tool has been pilot tested in four districts of Karnataka and in one district and one dairy cooperative (Mulkanoor dairy cooperative) in Telangana. Several state and district development officers and extension staff of dairy cooperatives, dairy industries and food industries, as well as ILRI scientific staff from countries outside India have been trained on the tool. Further trainings are being planned for wider use of the tool.

The tool is currently being used in different projects in Karnataka, Maharashtra and Tamilnadu states of India, and the response from field staff has been encouraging. An increase in milk production and reduction of feed cost have been reported.

Conclusion and way forward

Initial response from the farmers and the technicians using the tool has been good. Apart from giving guidance on balanced ration formulation, the tool can provide other useful information such as the quality of feed ingredients, quality of diet fed and greenhouse gas emission before and after feeding the balanced diets. It can be used to challenge the animal by manually adjusting the nutrient requirements for higher milk production, provided the genetic potential of animals allows. Climate-smart feeding strategies can be developed using the tool. The training and capacity building activities need strengthening especially in countries such as India, Bangladesh, Nepal, Thailand and Tanzania, which have ambitious plans to increase milk production.

2.3.2 Towards formulation of balanced rations: can ruminant metabolizable energy of barley, chickpea and lentil straw be predicted using chemical composition

Introduction

In the mixed crop-livestock systems, straw is key feed for livestock in terms of quantity and quality especially during the dry season. In the dry areas of west Asia and North Africa region, straw substitutes a considerable proportion of diets of sheep in summer and winter. Energy content of feeds is important to determine the optimal level of incorporation of the feeds into diets of ruminants. Metabolizable energy (ME) content of feed ingredients is widely used to formulate balanced diets, to achieve the targeted level of animal production. Feeding a balanced ration to livestock reduces cost of feeding, decreases greenhouse gas emissions and enhances productivity in addition to enhancing feed use efficiency.
This study (Alkhtib et al. 2019c) attempted to generate simple and robust models to predict ME content of barley, chickpea and lentil straw using chemical composition parameters (crude protein, CP; neutral detergent fibre, NDF; acid detergent fibre, ADF; acid detergent lignin, ADL) determined using near infrared reflectance spectroscopy.

**Salient findings**

The parameters: NDF, ADF, ADL and CP are poor predictors for straw ME in barley, chickpea and lentil, and a direct estimation of ME of these straws is still required.

**Conclusion and way forward**

The chemical composition parameters of whole straw are poor predictors of ME. Relationship between chemical composition and digestibility of straw is expected to be affected by morphological structure. Precise prediction of ME of straw might be achieved using morphology-based equations. On that account, prediction equations of ME of morphological fractions of barley, chickpea and lentil straws using chemical composition needs investigation.

### 2.3.3 OVERALL CONCLUSION, LESSONS LEARNT AND WAY FORWARD

A digital tool for formulation of balanced diets has been pilot tested and used in India. Training on the use of tool has been provided to several state and district development officers and extension staff of dairy cooperatives, dairy industries and food industries. The ILRI scientific staff from countries outside India have been trained on the tool, for use in other countries. More trainings should be conducted, for example for dairy development authorities in countries such as Bangladesh, Nepal, Thailand and Tanzania, which have ambitious plans to increase milk production. The tool reduces the cost of feeding and increases profit of the farmers. A spill over effect is enhanced feed use efficiency which also decreases methane emission from the dairy sector. Policy and institutional support that encourages farmers, extension and development workers of state departments, dairy cooperatives and private feed companies would help in scaling-up of the use of the tool. Inclusion of this subject (feeding of balanced ration: why and how) in the curricula of animal production and veterinary students and in para-veterinary trainings is also suggested.

For preparation of balanced rations that meet the production objectives, determination of metabolizable energy (ME) of barley, chickpea and lentil straws through chemical composition parameters has not been successful. However, equations using chemical composition parameters of different morphological fractions of these straws might predict their ME reliably, and this should be a subject of further research. Till then ME needs to be determined directly, for example using the *in vitro* Hohenheim Gas Method. The ME is an important input parameter in balanced ration formulation using the digital tool described in this section or the excel-sheet based least cost ration formulation.
2.4 CROP AND GRASSLAND RESOURCES – SUSTAINABLE MANAGEMENT

2.4.1 Competitive uses of crop residues – A sustainable perspective

Crop residues such as straws and stovers of cereals and pulses have several uses. Two major uses are livestock feed and mulch for enhancing soil nutrients. For sustained production of cereal and pulse grains and straws, proper soil health is vital. It is important that a balance is kept between the use of crop residues as livestock feed or as a mulch. Work conducted in this area is synthesised below.

2.4.1.1 Analysis of crop residue use for livestock and soil conservation in smallholder mixed farms in Ethiopia

Introduction

Crop residue (CR) is dual purpose resources in the mixed crop–livestock systems of the Ethiopian highlands. They serve as livestock feed and inputs for soil and water conservation. They are generated predominantly from cereals and pulses. However, in view of the allocation of CR, soil conservation and livestock are two competing enterprises. Identifying the determinants of the intensity of use of cereal and pulse residue may help in designing strategies for more efficient CR utilization. Determinants of the use of cereal and pulse residue for livestock feeding and soil mulching among smallholder farmers in the mixed farming system were analysed (Alkhtib et al. 2017b). Data on CR utilization was collected in two highland regions in Ethiopia from 160 households using a structured questionnaire.
Salient findings

The farmers prefer using CR from pulses over CR from cereals for livestock feeding purposes. The proportion of CR from pulses used as feed was positively affected by education level of the farmer, availability of livestock extension service, number of small ruminants and CR production from the previous season. Distance of farm plots from residences of the farm households negatively affected the proportions of cereal and pulse residue used for feed. The use of pulse residue increased significantly when the women participated in decision making.

2.4.1.2 Barley straw use for animal feed and soil mulch in Ethiopian highlands mixed crop-livestock systems

Introduction

Barley straw serves as livestock feed and mulch for soil and water conservation in the mixed barley-livestock systems of the Ethiopian highlands. High demand for barley straw biomass in the system creates competition between the two uses. A study (Keno et al. 2021) was conducted to determine the relative values of use of barley straw as mulch for reduced erosion compared to use as livestock feed/bedding and identify the characteristics of farmers more or less likely to use barley straw as mulch for soil conservation and as feed for livestock feeding. Data on the production and use of barley straw were collected from 236 households using a structured questionnaire. Use of the straw for the purposes of soil mulch at three levels, 0–15% (marginal mulching), 15–35% (optimal mulching), 35–100% (over-mulching), was analysed using a multinomial logit model.

Salient findings

The optimal proportion of barley straw used as soil mulch was positively affected by the educational level of the household head, family size, distance between cropping land and homestead, number of equines in the household and amount of straw production. Female-headed households were more likely to mulch less than the optimal amount of barley straw. In general, the more the farmer’s exposure to formal extension the less barley straw is used for soil mulching.

Conclusion and way forward

This study provides guidance for the proportional utilization of barley straw. This can help agricultural extension officers and other stakeholders design more targeted approaches to encourage farmers to use the optimal proportion of barley straw as mulch and as livestock feeding.

Generally, farmers tended to use barley straw for livestock feeding rather than for soil mulching. This is because farmers allocate barley straw to different uses based on the short-term benefits. Farming land in barley-livestock farming systems is, therefore, expected to deteriorate, leading to a decrease in grain and straw production. Formal extension outreach had a statistically significant effect on farmers’ greater use of barley straw as soil mulch.
2.4.1.3 OVERALL CONCLUSIONS, LESSONS LEARNT AND WAY FORWARD

Agricultural extension in the Ethiopian highlands should focus more on the long-term benefit of soil mulching to preserve soil health. Increasing the awareness among farmers about the superiority of the pulse residue over cereal residue as animal feed and encouraging use of cereal residue as soil mulch could optimize the utilization of crop residues. Capacity building and on-farm demonstrations that highlight the better feeding value of pulse straws over cereal straws should be strengthened.

Introducing new feed resources in crop-livestock farming systems would increase the feed supply to the livestock sector. This would increase the use of straws as soil mulch. Improving straw yield besides grain yield via breeding would increase the supply of straw not only to meet livestock feed needs but also provide enough crop residues for soil mulching. More studies on decreasing post-harvest losses in straws should be undertaken. This can be part of a process that could evenly distribute and effectively utilize crop residues in mixed farming system in Ethiopia as well as other regions of the world. Interventions, trainings and extension services promoting context-specific crop residue management for both agriculture and livestock components are imperative to facilitate the optimal utilization of straws and stovers in Ethiopian mixed farming systems. Conservation agriculture should also be cognizant of the use of crop residues as animal feed.

2.4.2 Food-feed crops – Sustainable management

Management practices such as cultivation practices, fertilizer applications, weeding and time of harvesting all have important roles in enhancing productivity of feed resources and human foods from food-feed crops. Two examples from the project, showing the impact of weed management and fertilizer application, are illustrated below.

2.4.2.1 Redesigning traditional weed management practices in faba bean fields to optimize food-feed production in the smallholder system

Introduction

The demand for livestock products such as milk and meat is increasing in Ethiopia as a result of increasing population, urbanization and rising income. The increasing demand for livestock products offers opportunities for smallholders to realize better livelihoods. Despite the growing demand for livestock products in Ethiopia being well recognized, the sector has not been able to produce adequate livestock products to satisfy demand. Shortage of adequate supplies of quality feeds is one of the major constraints to increasing livestock productivity.

It has been reported that farmers in Southern and Amhara regions of Ethiopia have a traditional practice of deliberately weeding their faba bean (Vicia faba L.) fields much later than is recommended by the extension system. They use the weed herbage mass from the faba bean fields as a livestock feed during the main cropping season when stubble grazing is unavailable, and crop residue stocks are low. The bulk
of this weed herbage mass is composed of grass volunteers from cereals and broadleaved weeds that emerge and grow within the tilled part of fields. A new intervention for intensification of agriculture, including livestock built on the local knowledge and traditional systems, has a better chance of success. Therefore, it is vital to examine the rationale behind farmers’ practice of deliberately weeding faba beans late and explore options to further improve overall productivity. The study (Bezabih et al. 2021) involved comparison of the overall benefit from the traditional weed management regime against the frequent weeding recommendation. In addition, the study also evaluated a related issue: whether intercropping forage oat (Avena sativa) with faba bean crop can increase overall food and feed production to better meet the demands of smallholders.

**Salient findings**

The improved weed management increased grain yield (2.49 vs 2.12 Mg/ha) compared to the traditional management regime. But the traditional management produced higher (P < 0.01) weed forage biomass (2.12 vs 0.27 Mg/ha) compared to the improved. The analysis showed the opportunity costs associated with the loss in weed forage biomass were not convincingly offset by the economic gains from increased grain yields.

In the second experiment, grain yield was again highest for the improved weed management. The intercropping faba bean with oat forage has a potential to increase the gross income that farmers derive from their faba bean farms by approximately 8%, providing much needed forage for livestock during the main cropping seasons. The land equivalent ratio was above unity for all faba bean varieties. This indicates that the intercropping practice can contribute to land productivity, reducing the area required by a factor of 1.08 to 1.33 to produce the same quantity of yield that can be obtained using the sole cropping practice.

**Conclusion and way forward**

Farmers’ decisions not to weed frequently have a rational economic basis and they give high importance to their livestock. Capitalizing on the existing indigenous weed management practice would help to identify adoptable intensification strategies. Building on this traditional practice, one of the examples is that the intercropping of improved forage oat with faba bean would allow to further enhance forage production (double than that from weeds) with little compromise on faba bean yield. In addition, the intercropping practice can contribute to land productivity, reducing the area to produce the same quantity of yield that can be obtained using the sole cropping practice. Overall, the intercropping management provides greater benefit over the traditional management practice. Wider dissemination of the results and promotion of the intercropping of forage oats and faba bean as food-feed crops are needed.
2.4.2.2 Improvement in food-feed traits of grain legumes and use of legume haulms in mixed crop-livestock systems of Ethiopia

Introduction

Grain legumes play an important role as a source of food and feed in smallholder mixed systems. They also contribute to soil fertility improvement through biological nitrogen fixation. A survey conducted in Ethiopia showed that the main use of grain legume haulms (76.3% by mass) was as a source of livestock feed and about 89.8% of the interviewed farmers reported increasing trends of using haulms as a livestock feed in the studied districts (Sisay Belete et al. 2021). Mixing of haulms with cereal straws during feeding and conservation of the haulms for dry period use were practiced by 62.2% and 60.1% of the respondents, respectively. Although rhizobium inoculation and phosphorus fertilizer are known to improve grain yield of legumes, information is limited on the effect of this practice on the yield and fodder quality of the haulm.

A study (Belete et al. 2019) was conducted to evaluate the effects of rhizobium inoculation (I) and phosphorus fertilizer (P) on yield and nutritional quality of grains and haulms of grain legumes (faba bean, chickpea, common bean and soybean) on farm across diverse agroecological locations in the Ethiopian highlands. The crops were subjected to four treatments (+I, +P, −I+P and a negative control (−P−I)) at multiple locations.

Salient findings

The treatments significantly (P < 0.05) increased grain yield (an increase of 30%) for all studied crops and there was a 28% increase on haulm dry matter yield for faba bean, common bean and soybean. CP and IVOMD values of haulms of these crops increased (P < 0.05); and NDF and ADF contents decreased. The haulm CP content and IVOMD of chickpea also responded positively (P < 0.05) to the treatments.

Conclusion and way forward

The application of rhizobium inocula and P fertilization can be used to improve both yield and quality of grains and haulms of grain legumes. This practice offers an opportunity for smallholders in the crop-livestock system to improve the food-feed traits of grain legumes with minimal input and environmental footprint. To boost the role of grain legumes production in the mixed crop-livestock production system of Ethiopia, smallholder farmers’ need to be supported technically and institutionally with promotion of technologies which have potential to improve grain for human consumption and haulm for animal nutrition.

2.4.2.3 OVERALL CONCLUSION, LESSONS LEARNT AND WAY FORWARD

Following of the traditional weeding practices by farmers has a rational economic basis because they give high importance to their livestock. Although there was increased grain yield with the practice that involved frequent weeding, the opportunity costs associated with the loss in weed forage biomass were not
convincingly offset by the economic gains from increased grain yields. Capitalizing on the existing indigenous weed management practice that relies on the importance the farmers give to the use of biomass as livestock feed would help in adopting intensification strategies. Towards this end, one of the examples is that the intercropping of improved forage oat with faba bean, which allows to further enhance forage production (double than that from weeds) with little compromise on faba bean yield. In addition, the intercropping practice can contribute to land productivity, reducing the area to produce the same quantity of yield that can be obtained using the sole cropping practice.

2.4.3 Grassland feed resources – Sustainable management

In tropical production systems grasslands constitute the main sources of nutrition for domestic and wild herbivores. These also provide essential ecosystem services by reducing soil erosion and improving rainfall infiltration and carbon sequestration. Grazing land resources are shrinking, because of intense degradation, as a consequence of deforestation, agricultural land expansion and continuous heavy grazing. Consequently, livestock are forced to concentrate on very limited grasslands, which in turn results in reduced productivity. Enhancing biomass production and their sustainable use are vital. Work conducted under the project in this area is briefly discussed below. These deal with enhancing productivity through application of fertilizer, effect of grazing management and biomass yield, nutritive value and methane production of some forages in Ethiopian grasslands.

2.4.3.1 Productivity and herbage quality of native pasture in degraded tropical grasslands in response to fertilization application

Introduction

Grasslands remain the main source of feed for ruminant livestock in the developing world. Apart from serving as a source of feed for livestock, well-managed grasslands provide essential ecosystem services by reducing soil erosion and improving rainfall infiltration and carbon sequestration. In Ethiopia, although more than 50% of the feed resource is derived from natural pastures, the productivity of grazing lands has decreased over the years due to overgrazing resulting in land degradation, loss of soil fertility and proliferation of invasive species, which contribute to critical seasonal feed shortages.

Soil fertility depletions coupled with climate change have affected the composition of native pasture species, resulting in less palatable pasture species dominating the available grasslands. To use the available grasslands judiciously, it is essential to improve the way grasslands are managed. As nutrient mining is one of the reasons for declining soil fertility in grasslands, the application of context specific fertilization practices will likely result in an immediate positive impact on native pastures as well, resulting in improved productivity and quality while diversifying household income from the sale of surplus fodder.

Direct addition of nutrients can be achieved by using mineral or organic fertilizers, or a combination of both nutrient sources. Therefore, a study (Bedaso et al. 2021) was conducted to evaluate the response of degraded natural pasturelands in terms of species composition, forage yield, and quality to the application
of different types of fertilizer. The study sites were two districts in the central Rift Valley of Ethiopia with contrasting agroecologies. The treatments were control (no application of fertilizer), commercial fertilizer (50 kg urea/ha and 100 kg diammonium phosphate [DAP]/ha), cattle manure (7.5 t/ha), wood ash (3 t/ha) and lime (7.5 t/ha). The hypothesis was that application of fertilizers would narrow pasture yield gaps and improve feed resource availability and household income.

**Salient findings**

Soil physical properties were not altered following the fertilization inputs, but chemical properties were affected. Soil total nitrogen increased from 0.11% to 0.32% following the application of cattle manure. The pH increased from 5.9 to 7.3 with wood ash application. Herbage dry matter yield increased from 1.88 t/ha to 6.65 t/ha with chemical fertilizer. The herbage crude protein content increased significantly from 96 g/kg to 157 g/kg with manure application. On the other hand, the neutral detergent fibre tended to decrease following manure application. The application of fertilizer not only improved the yield performance, but also favoured the growth of desirable pasture species.

Partial cost-benefit analysis indicated a positive economic gain from the direct sale of pasture hay for all treatments except for lime. The seasonal price differences suggest that selling the hay during the dry season can increase net benefit for farmers by approximately 16–22%. The analysis also showed that farmers can triple their income if they apply commercial fertilizer on their pastureland compared to the control. Manure and wood ash applications also increased the estimated income by 2.0 and 1.6 times, respectively.

**Conclusion and way forward**

The application of fertilizer inputs on to degraded grasslands can lead to a doubling or tripling of native pasture yield with improved nutritional quality and economic benefit for smallholder farmers. The fertilizer applications present an opportunity to improve livestock productivity by increasing the quantity and quality of the forage produced from overgrazed grasslands. If the farmers harvest the pasture and store the hay until the dry season, the time when the prices are high, the gross economic gain can increase two to three fold. Also, compared to the economic benefits from production of food crops such as wheat and maize, it appears that the return from the improved pasture production is economically attractive. However, more studies are required to prove this.

The application of chemical fertilizer appeared to provide the maximum short-term benefit in terms of yield and economic gain, manure and wood ash applications can provide modest benefits with likely extended soil fertility benefits. Future studies should consider multiple season observations and application rates based on the soil analysis. Wider adoption of such grassland management practices requires a strong extension services and on-farm demonstration.

**2.4.3.2 Vegetation structure, aboveground biomass and soil quality in response to traditional grazing land management practices in the central highlands of Ethiopia**
Introduction

Grazing is the predominant form of ruminant feed in the most parts of the extensive and smallholder mixed crop-livestock systems of Ethiopia. Fallow lands, permanent pasturelands during cropping season and croplands after crop harvest are among the dominant grazing areas. Grazing land resources are shrinking, because of intense degradation, as a consequence of deforestation, agricultural land expansion and continuous heavy grazing. Consequently, livestock are forced to concentrate on very limited pastureland, which in turn results in reduced productivity in the long run and makes the mixed crop-livestock system unsustainable. To utilise the available grazing lands in a sustainable manner, it appears important to evaluate the impacts of different traditional grazing land management practices for implementing knowledge-based grazing land management strategies.

Two traditional grazing land management practice sites, enclosure during wet season (known as kalo) and the adjacent open access grazing land (known as free grazing) were selected to quantify changes in vegetation structure, aboveground biomass yield and soil quality attributes in response to traditional grazing land management practices in mixed crop-livestock system in the central highlands of Ethiopia (Wegi et al. 2021).

Salient findings

Aboveground biomass yield for the grass species was 17.6% and 31.2% higher, respectively, for the highland and mid-highland agroecologies for enclosed areas, compared with open-access grazing. *Andropogon amethystinus* (Important value index (IVI) = 86.9) and *Pennisetum thunbergii* (IVI = 79.2), the most dominant and highest density, found in the enclosed areas decreased from open access grazing land and replaced by more resistant to continuous heavy grazing, like *Eleusine floccifolia* (IVI = 125.7) in the mid-highland area.

Herbaceous species richness was better in open access grazing land than the enclosed areas. Soil quality parameters, such as total nitrogen, available phosphorous, calcium, sodium and cation exchange capacity, were significantly higher for enclosed areas than open access practice.

Conclusion and way forward

Because of overgrazing, resulting from continuous uncontrolled stocking, the biomass yield decreased significantly in an open access grazing area and this led to land degradation. The abundance and density of some palatable and dominant perennial grass species in the enclosed areas were lower than that from open access grazing land, due to inability of the species to tolerate continuous stocking. The stress of continuous stocking in an open access grazing land also decreased soil quality parameters, which in turn affected productivity of the grazing land. Enclosures had a positive effect in increasing grazing land productivity and maintain soil fertility. Implementation of enclosure practices would play an important role in increasing feed resource availability from, and environmental sustainability of, the grassing land. This system needs promotion for use at a wider scale.

2.4.3.3 Botanical composition, biomass yield, nutritional quality and methane production of forages in highlands of Ethiopia
Introduction

In tropical production systems grasslands constitute the main sources of nutrition for domestic and wild herbivores. Grasslands are characterized as lands dominated by grasses rather than large shrubs or trees. However, grasslands do also contain a diversity of other herbs. Grasslands account for about 30% of the land cover worldwide and constitute 55% of feed resources for livestock in Ethiopia. The ability of grassland to provide forage as an important source of nutrients for livestock productivity depends on both their above-ground net primary productivity and the nutritional value of the available vegetation. Methane emission from ruminants depends on the type of forages they are fed. Methane is a greenhouse gas and its emission from ruminants represent a loss (up to 15%) of digestible energy to the animal. The carrying capacity of grasslands also depends on the forage yield and quality. A study (Mosisa et al. 2021) was conducted to assess botanical composition, biomass yield, nutritive value and methane production of forages in the grasslands of Kofele district in west Arsi Zone of Oromia National Regional State, southern Ethiopia. Three patches of the grassland including protected grassland, private grazing land used by smallholder farmers and ranch were selected to represent three different grazing land management practices.

Salient findings

Out of 17 browse species identified in the ranch, 47.1% were trees while 52.9% were shrubs. The total biomass production from protected grassland (4.34 t/ha) was significantly higher than that of private grazing land (3.66 t/ha) and ranch (3.76 t/ha). Biomass production of sedge and forbs were the significantly highest in ranch. The ranges of chemical constituents for grasses were 8.44–10.74%, 52.8–72%, 27.7–37.4%, 3.1–5.6%, 58.2–76% for CP, NDF, ADF, acid detergent lignin (ADL) and in vitro dry matter digestibility (IVDMD), respectively. The CP and IVDMD for legumes varied from 15.64–20.33% and 80.1–85–1%, respectively. For browses the ranges of CP and IVDMD were 15.41–27.19% and 57.4–81.9%, respectively. Among grass species, Eragrostis botryodes generated less methane. In general, legumes (5.5–6.5 mL/200 mg) and sedge (6 mL/200 mg) produced less methane compared with grasses (7–10.5 mL/200 mg). Browses (9.5–13.5 mL/200 mg) produced more methane compared with herbaceous species (5.5–10.5 mL/200 mg). The protecting grassland and using cut and carry feeding system promoted more herbage production.

Conclusion and way forward

Compared with ranch where animals were allowed to graze without any restriction and private grazing land where tethering is practiced, exclusion of animals from grassland throughout the grazing season (protected grassland) and feeding animals in the form of cut and carry system promoted better yield. Generally, the CP content of browses was high, but methane emission from them was higher. Due to the high CP content these browses could be used as supplement to poor quality grasses. The use of legumes with grasses and other browse species is suggested as a feeding strategy to reduce methane emission.
However, further studies to evaluate animal performance responses are required to explore the potential of these feed resources.

**2.4.3.4 OVERALL CONCLUSION, LESSON LEARNT AND WAY FORWARD**

The application of fertilizers offers an opportunity to improve livestock productivity by increasing the quantity and quality of the forage produced from overgrazed grasslands. The pasture yield can increase two to three-fold with improved nutritional quality and economic benefit for smallholder farmers. The hay prices increase two or three-fold in dry season. The gross economic gain to the farmers can be increased by harvesting the pasture and storing the hay until the dry season. However, additional economic studies are required to compare the profits from selling hay in the dry season with those from maize or wheat cultivation.

While chemical fertilizer application appeared to provide the maximum short-term benefit in terms of yield and economic gain, manure and wood ash applications can provide modest benefits with likely extended soil fertility benefits. The study under reference was conducted in only one season due to logistical reasons, and it was not possible to objectively quantify the extended benefits in terms of improvement in soil reaction and organic matter accumulation. It is thus important that future trials and practical application consider multiple season observations and application rates based on prior soil analysis results. In addition, for wider adoption of such grassland management practices, strong extension support and a series of demonstrations to livestock producers will be important. This would help to ensure sustainable improvement in pasture productivity and soil fertility of degraded pasturelands.

The grazing management practices had a strong impact on biomass yield and composition. The enclosed areas performed greater in most of the parameters considered than open access grazing land management practices. The above ground biomass yield decreased significantly in an open access grazing area, because of overgrazing resulting from continuous uncontrolled stocking. This resulted in land degradation. The abundance and density of some palatable and dominant perennial grass species in the enclosed areas decreased from open access grazing land, because of the inability of the species to tolerate continuous stocking. The stress of continuous grazing in an open access grazing land also decreased soil quality parameters, which in turn affect grazing land productivity. Enclosures had a positive effect in increasing grazing land productivity and maintain soil fertility. Therefore, in a scenario of declining grazing land, implementation of enclosure practices would play an important role in increasing feed resource availability, environmental sustainability and productivity of the farming system. This system may be promoted for use at a wider scale.

Generally, variations among the grassland sites in terms of species composition, biomass yield and nutritional qualities of forages existed. Exclusion of animals from grassland throughout the grazing season (protected grassland) and feeding animals in the form of cut and carry system were good in promoting better pasture yield compared with ranch where animals were allowed to graze without any restriction and private grazing land where tethering is practiced. Generally, the crude protein content of browse
was high, but more methane was generated from the browses. Due to the high crude protein content these browses could be used as supplement to poor quality grasses. When nutrients are synchronised as is expected on supplementing browses with poor quality grasses, microbial protein production increases and the methane emission decreases. The use of legumes and browses with grasses is suggested as a feeding strategy to reduce methane emission. Further studies to evaluate animal performance responses are required to explore the potential of these feed resources.
2.5 FEED AND FEEDING INTERVENTIONS IN INDIA AND TANZANIA

2.5.1 Introduction

Milk is an important commodity in India and Tanzania, and rising demand, especially in the cities, is an opportunity for farmers to intensify milk production. The lack of sufficient good-quality feed is a key constraint for the sustainable improvement of milk yields and smallholders’ income in both these countries. Such constraints have usually been addressed by promoting improved feed technologies, but these have rarely been scaled. This calls for development and use of new approaches.

The research for development project ‘Enhancing Dairy-based Livelihoods in India and the United Republic of Tanzania through Feed Innovation and Value Chain Development Approaches’—or ‘MilkIT’—focused on improving smallholder livelihoods through dairy feed innovations in India (Uttarakhand state) and Tanzania (Morogoro and Tanga regions). The project used several novel tools and approaches to identify challenges and provide solutions (Lukuyu et al. 2015). The work was spearheaded by ILRI, International Centre for Tropical Agriculture, Sokoine University of Agriculture in Tanzania and the Tanzania Livestock Research Institute, and was conducted jointly with several national stakeholders including development and extension authorities of Uttarakhand state in India and of Morogoro and Tanga regions in Tanzania. IFAD also participated in one of the activities (introduction of troughs).

The project combined a series of approaches to improve feed supply, including establishing ‘innovation platforms’ and bringing on board milk producers and other actors of the dairy value chain; applying simple diagnostic tools for feed within the broader context of the production system to guide intervention strategies; and identifying and dealing with value chain constraints. By using these processes, the project
placed feed in a broader context, recognizing that enhancing feed supply has both technical and institutional dimensions.

In India, the Feed Assessment Tool (FEAST; Box 1) was used in both target and control communities, before and at the end of the project, involving the same households, to collect quantitative information to assess the project impact. This allowed the resulting data to be used as a biophysical baseline. Qualitative assessment using focus group discussions helped in identifying the most important feed issues and in initiating the discussions on how to solve them.

In Tanzania, FEAST was used early in the project to characterize the livestock production system and identify various feeding issues in the study sites. The results of the assessment were reported to the innovation platforms. The platform discussions led to a series of feed interventions for applying in the project sites.

**BOX 1. What is FEAST?**

FEAST is the shortform of ‘feed assessment tool’, which poses tried-and-tested questions and allows project staff and partners to quickly and systematically identify key feed related challenges and possible practical interventions to address them. It helps local stakeholders decide which interventions can optimize feed utilization and animal production.

2.5.2 Salient findings

2.5.2.1 Constraints identified

Major constraints in the feed value chain were identified in the project sites in India and Tanzania.

**India.** The main feed-related constraints were inadequate availability of concentrate and wastage of fodder. Other constraints identified were the lack of knowledge of farmers on appropriate feeding dairy animals, limited artificial insemination services (especially for buffaloes), limited and low-quality grazing biomass on grasslands and high cost of grass sourced from other areas.

**Tanzania.** At a broader landscape level, the major constraints concerned the inefficiency of forage seed systems, inefficacy in the supply of compounded feeds, and limited access to and quality of water. On the other hand, the assessment also showed potential opportunities in the emerging feed and fodder markets. At the farm level, the broader key constraints identified using FEAST were insufficient forage availability, poor livestock housing, land shortage and a lack of improved breeding bulls. These topics were the entry points for discussion at the village innovation platforms.

The discussions further led to identification of major constraints that limited feed production, which were: 1) fluctuations in feed quantity and quality as a result of seasonality, quantity and access to drinking water
over time; 2) overstocking by pastoral communities, resulting in degradation of pastures and lack of grazing reserves for the dry season; 3) poor quality of pasture, fodder and crop residues; and 4) limited supply and access to forage seed and planting materials.

2.5.2.2 Solutions proposed

Through discussions at the innovation platforms, a series of interventions emerged in both countries.

**India.** The interventions emerged were: 1) use of improved feed troughs to reduce feed wastage during feeding; 2) introduction and promotion of dual purpose crops (winter cereals) to increase fodder availability in winter; 3) increase in cultivation of fodder grasses to increase green fodder availability in summer; 4) introduction of smaller and women-friendly chaff cutters to overcome problems faced by women in operating the usual heavy, mechanized, wheeled machines; 5) training and awareness-raising on using concentrates to enhance concentrate use; and 6) establishing links with private feed companies to increase access to, and reduce cost of, concentrates.

**Tanzania.** The village platforms identified various technical and capacity-development interventions to improve year-round production. The emerged interventions were: 1) introduction of improved cut-and-carry forages to enhance herbage production in intensive systems; 2) improve agro-pastoralists’ dry-season grazing reserves (locally known as ololili) and feed conservation strategies to overcome dry season feed shortages in extensive systems; 3) feeding of adequate feed rations, enabling increased expression of cattle’s genetic potential to increase milk production; 4) training on feed ration formulation, forage establishment, management and use to encourage adoption of introduced technical interventions to increase production; 5) training on feed conservation to overcome dry season feed shortages in intensive
systems; and 6) introduction of new designs of cattle sheds to improve cattle comfort, hygiene and husbandry and enhance feed utilisation.

2.5.2.3 Solutions implemented

A wide range of feed and feeding technologies were introduced in India and Tanzania.

India

In India, women-friendly chaff cutters, improved feed troughs and improved forages were introduced, and links between the feed companies and dairy farmers were strengthened.

*Introduction of chaff cutters.* Introduction and testing of simple chaff cutters in the form of weighted knives and mounted scythe cutters (sourced from Gandhi Ashram and Gujarat dairy cooperative (AMUL) in India) showed good results. The farmers found them easy to use. A local entrepreneur was identified to manufacture the chaff cutter. A total of 225 women farmers adopted the feed choppers.

*Introduction of improved trough.* To reduce feed wastage on farms, low-cost troughs, costing US$67 were designed. The farmers were offered a loan and subsidies through the innovation platforms to encourage them to make such troughs. The use of the troughs reduced feed and fodder wastage by 20–30%. The reduction in wastage decreased the amount of women’s work in multiple ways: 1) in collecting less fodder from the forest; 2) by eliminating the need to rearrange fodder around the animals to stop them from trampling on it and soiling it; and 3) by precluding the clearing of the waste fodder from the cattle sheds. In addition, clean fodder, free of urine and dung, because of using the troughs, reduced the risk of infections for the animals. A total of 130 farmers built the improved troughs.

A cost-benefit analysis of using both the chaff cutter and the improved trough showed that they were profitable for small-scale farmers. Total net gain over five years was Indian rupees 5430 per farmer.

*Introduction and promotion of improved forage.* Dual-purpose crops (wheat, barley and oats) and temperate grasses (tall fescue, Festuca arundinacea (dholni), Orchard grass or cock’s-foot grass, Dactylis glomerata (kucchi), Perennial rye grass, Lolium perenne, Smooth brome grass, Bromus inermis to increase green fodder in winter, and improved forages (Napier grass, setaria and berseem clover) for the summer, were introduced with varied results.

Although seed of the dual-purpose crops costed one and a half times more than common local crop varieties (wheat, oats and barley), farmers adopted them quickly because they could collect and sow the seed for three to five years without a significant drop in yield. Also, the dual-purpose varieties allowed harvesting them as a fodder at 79–85 days after sowing in the winter to produce ‘bonus’ green fodder. The crop then regrew and was taken to maturity with no detrimental impact on final yield of grain or straw.
The forage grasses were successful only in the areas where there was enough water. Setaria grass failed to germinate in all sites due to lack of water, and the seeds were expensive. The seed of the temperate grasses were also reported to be expensive and they performed poorly. Berseem clover was successful in irrigated areas but failed in areas where access to water was limited.

Farmers with local breeds showed less interest in planting fodder crops because of the high cost of seed and low productivity of their animals; the investment was found to be not worthwhile. Uptake of forages depended on farmers having high-yielding animals. The farmers who had planted improved forages were able to feed their cattle for longer than those who relied on local forages.

**Linkages to improve access to concentrate feed.** Concentrate was scarce and expensive in the project area because it had to be transported from faraway places. Demand for concentrate was higher in areas having high-yielding crossbred animals. Through the innovation platform, establishing linkage with a dairy cooperative and a private feed company led to resourcing concentrate in bulk at a reduced cost. This additional concentrate boosted milk production. However, the concentrate feeding did not increase milk production in the low-yielding local breeds.

**Tanzania**

![Farmers at a community plot are planting different improved forages to boost livestock productivity and lower their environmental impact. Photo Alliance of Bioversity International and CIAT/Georgina Smith](image)

The focus has been on introduction of cultivated forages and good feeding practices.

**Introduction and promotion of cultivated forages.** In zero-grazed intensive and semi-intensive systems, various combinations of improved Napier grass varieties and legumes were introduced. Fodder trees and shrubs were also planted as hedges for providing seedlings to other farmers. Improved forages introduced
were Napier hybrid, Napier Kakamega II, green leaf Desmodium, Mulberry, *Gliricidia sepium*, and *Canavalia brasiliensis*. Silage making was introduced to conserve forages and reduce seasonal fluctuations in their availability and the impact was found to be positive.

Forages that give higher herbage were better accepted. Farmers appreciated the introduced forages because they saved work and time in collecting natural grasses from roadsides and/or fields. The number of farmers that introduced the forages tripled in one year, from 25 to 87.

In extensive systems, buffel grass (*Cenchrus ciliaris*) and legumes were introduced to improve the quality of the conserved pastures. Pastures in the enclosures is a traditional forage-conservation method used by the Maasai and other pastoralists in Tanzania in which land around homesteads is fence off. The agro-pastoralists were trained in pasture establishment, management and utilization. Forages *in situ* in the enclosures were used during the dry season (when feed is scarce) by lactating, pregnant and weak animals as well as calves that were left behind when the herds migrated to greener pastures. These feed reserves helped to avoid grazing of animals on cropland, decreasing disputes between the crop growers and livestock keepers.

*Adequate feed ration provision*. An 106% increase in milk production, from 6.6 to 13.6 litres/cow/day, was obtained by introduction of good feeding practices through capacity development and by providing concentrate feed. The final milk yield was 90.6% of the assumed genetic potential (15 litres). Training on conservation of natural grasses in the form of hay, by using a box-baler, led many farmers to produce hay from natural grasses and maize stover. The use of box-balers was accelerated through farmer-to-farmer informal information exchanges and trainings. Cross-visits among platform members stimulated farmers in surrounding villages to make their own hay balers. The number of farmers using this method of conservation reached 68 in one year.

2.5.3 CONCLUSION, LESSONS LEARNT AND WAY FORWARD

‘Top-down’ approaches often do not work in the application of feed interventions. Context-specific identification and application of feed intervention led to higher and sustained adoption. Use of the feed assessment tool, FEAST and the innovation platform approach stimulated engagement with farmers and other stakeholders and helped in identifying appropriate context-specific feed interventions and in building ownership of the interventions. When implementing interventions, it is important to consider the context, production systems and agroecological conditions.

Having the right stakeholders in the innovation platform is key to identifying livestock- and feed-related challenges and their solutions. It is suggested to start off with many institutions for identification of the focus areas. Thereafter, based on the identified focus areas, the number of institutions can be scaled down to the relevant ones, and as new topics emerge, other members can be brought on board.

In India, availability of water was one of the main determinants for adoption of the improved forage cultivation and of the feeding practices based on them. The improved feed troughs were widely adopted.
Technical backstopping and support by the development workers and researchers proved important for the successful application of the interventions. Strengthening linkages of the farmers to the market acted as a catalyst to the adoption of forage-based feeding strategies.

In Tanzania, both for the extensive and intensive systems, the focus of the interventions was to increase forage production, but the approaches used were different. In the extensive system, less-water demanding quality forages were introduced in the enclosures used as feed banks for the dry period, while in the intensive system quality forages were planted. These approaches helped in realising the desired results.

The lack of improved seed and other planting materials was a serious constraint in Tanzania and India. The shortages seem to be because of poor coordination in the supply chain, discouraging potential adopters from taking up the technology. Similarly, the high cost of seed and low germination rates hindered the adoption of improved forages in both countries. Clearly, seed production and distribution network needs strengthening to increase farmers’ use of quality forages.

Hay production using box-balers was introduced and widely accepted. Increased market opportunities for selling forages increased the adoption of forage-based feeding strategies, showing the advantage of having a market pull. Market pull was found to be the key in giving momentum to, and sustaining, the application of feed-based technologies. Feed-related interventions must be aligned with other good husbandry practices, such as good housing that enhances farm and animal hygiene and comfort, and use of the trough to avoid feed wastage and health related issues, among others. The innovation platforms provided a means to train smallholders on general husbandry and improved housing structures. The organization and functioning of the platforms can, nevertheless, be improved. The participating institutions seemed to concentrate on disseminating the technologies emerging from the innovation platforms, rather than embracing the technologies along with the innovation platform approach. Policies and institutional reforms that establish criteria for identifying institutional priorities and mandates need revisiting.

In summary, this section presented five interconnected issues:

1) a feed base prototype that estimates feed availability, feed requirement and feed balance. Efficient use of feed resources requires knowledge of these parameters, following the famous management quote: ‘If you cannot measure it, you cannot manage it’. This prototype can be adapted for use in other developing countries.

2) strategies for improving basal diets. The technologies used for second-generation biofuel production could convert crop residues to concentrate-equivalent feed resources. Also, a widely experimented and used concept of supplementation, that attempts to provide complementary nutrients to rumen microbes to increase their activities, enhances nutrient availability to the host animals from basal diets.
3) use of digital tool that helps in preparing balancing diets i.e. diets that deliver protein, energy, vitamins and minerals in the right amounts required by animals for achieving the production target. As spill over effects of feeding the balancing diets are the higher feed use efficiency and lower greenhouse gas production.

4) crop and grassland management practices that dealt with the competitive uses of crop residues as animal feed and mulch, and weed and fertilization management of food-feed crops.

5) applications of the feed assessment tool — FEAST — and the innovation platform approach to identifying appropriate context-specific feed interventions and solutions.

This subsection highlighted the use of low-cost feed troughs and feed choppers in India and Tanzania that decreases feed wastage and enhance feed intake. Taking together, research and development work on all these five issues increased efficiency of feed utilization.
SUSTAINABLE RANGELAND MANAGEMENT AND REHABILITATION – SILVOPASTORAL SYSTEM

West Asian and North African rangelands represent a large and ecologically important land-use type that are characterized by arid or semi-arid climates with low and unpredictable precipitation, as well as variable air and soil temperature patterns. These lands provide a diversity of ecological services (for example nutrient cycling, carbon sequestration, pollution filtering, soil stabilization and the preservation of unique plants and animals) that are socially and economically important, providing an important forage resource for livestock production and sustaining local pastoral communities and culture. Complex political, socio-economical and environmental interactions have led to the progressive degradation of West Asian and North African rangelands over the past century. This degradation has been exacerbated by poor rangeland planning, insufficient implementation of appropriate land management practices and the unsustainable use of limited resources such as water, forage and soil. Additionally, these impacts have been amplified by harsh environmental conditions such as frequent and prolonged drought.

This section is sub-divided into: 1) Impact of climate change and grazing pressure on rangelands and their restoration using sustainable grazing practices and through characterization of native species, and 2) Managing rangelands through introduction of drought and salt-tolerant species.
3.1 IMPACT OF CLIMATE CHANGE AND GRAZING PRESSURE ON RANGELANDS AND THEIR RESTORATION USING SUSTAINABLE GRAZING PRACTICES AND THROUGH CHARACTERIZATION OF NATIVE SPECIES

ICARDA has extensively worked on strategies to restore the degraded lands and to better understand the impact of climate change and grazing pressure on the state of rangelands in west Asia and North Africa. Some major studies in these areas are synthesised in this section.

3.1.1 Climate change and grazing pressure on shrub communities of West Asian rangelands

Introduction

A study was conducted to evaluate the vulnerability of the important rangeland shrub, *Atriplex leucoclada* (Boiss) to both climate change and livestock grazing, within the Syrian rangelands as a representative landscape type of west Asia (Louhaichi et al. 2019c). Ecologically based quantitative niche models were developed for both shrub species using maximum entropy and 13 spatially explicit Geographic Information System-based layers to predict current and future species distribution scenarios.

Salient findings

The models depicted that the climatic variables vary over time, and that with grazing and climate change, the distribution of *A. leucoclada* will be reduced by 54% in 2050, with the mean annual and minimum temperatures of the coldest month having the highest contribution in the model (28.7% and 21.2%, respectively).

The contribution of the grazing pressure, expressed by the overgrazing index, was estimated at 8.2%, suggesting a negative effect of grazing and climate change on species and plant community resilience (recovery potential of a plant community). The other variables associated with landform, i.e. geomorphology and soil conditions, present at the site contributed little in explaining species distribution trends and patterns.

Conclusion and way forward

The studies have illustrated that the interaction of climate and increased grazing has the potential to favour the establishment of unpalatable species, while reducing the distribution of preferred plant species on western Asia rangelands. The restoration and rehabilitation of degraded rangelands may be impaired by the combined effects of climate change and human related activities (i.e. grazing pressure). These elements may result in altered ecosystems. This pattern continues to provide one of the greatest challenges to the management of arid rangeland landscapes. This is shown by reduced ecological resilience and the potential transition of landscapes across ecological thresholds that are dominated by undesirable plant communities and slow ecological processes.
The unique contribution provided by this study is the application of models for characterizing the suitability of two arid shrub species, which are well adapted to the current and future climatic patterns. This information can be used by managers to determine the risk associated with change in current vegetation distribution of desired native plant species because of over utilization. Also, it can be used to predict how these changes will impact rangeland ecosystem structure over time. The impacts described from the models used warrant a clearer focus on how monitoring across a species’ range can act as an early detection system for identifying potential climate change impacts. To validate and further refine these models, additional studies are needed that investigate the physiological thresholds, because of climate change scenarios, as well as disturbance intensities, for individual species of interest or value.

3.1.2 Revival of traditional best practices for rangeland restoration under climate change in the dry areas: A case study from southern Tunisia

Introduction

Grazing remains the most extensive land use in southern Tunisia because it is so inextricably linked to livestock income. But the rangelands have suffered many decades of severe degradation due to profound socio-economic changes and the emergence of an agro-pastoral society in place of the former pastoral one. Traditional grazing systems (gdel and herd mobility; gdel is a traditional historical rangeland governance practice), which had historically allowed for grazing deferment and control of grazing livestock, were abandoned. Yet grazing management strategies are important tools to sustain integrated livestock rangeland production systems in dry areas in the face of ongoing climate change and human pressure.

A study (Belgacem et al. 2019) was conducted to assess the best practices inspired by the traditional rangelands management concepts in a representative community. Total plant cover, species composition, flora richness and range production were determined in six rangeland sites subjected respectively to one, two and three years of rest; one and two years of light grazing after rest; and free grazing (control).

Salient findings

The dry rangelands keep their resilience to the negative effects of climate change once human pressure is controlled. A maximum of two years of rest is enough to sustainably manage the rangelands in southern Tunisia because this protection showed considerable and positive effects on the total plant cover, species composition, flora richness and range production.

A protection period of three years is neither sufficient for disappeared species to return, nor for succession to reach a new stage, particularly in the degraded Stipa tenacissima community. The reintroduction of the rest practice of gdel seems to be beneficial and a suitable tool to restore and mitigate degradation of arid rangelands under changing climate.
Conclusion and way forward

Rangeland vegetation was able to respond positively in terms of a range of desirable attributes following rational grazing. During short-term rest from grazing (two years), vegetation cover, density, rangeland production and carrying capacity can be improved. During relatively rainy years, grazing for short periods (one year or less) is apparently not harmful for rangeland vegetation in dry areas. In this context, if rangelands are grazed by several animals lower than the carrying capacity, there will be no risk of rangeland degradation. Adequate grazing can have a beneficial effect over the duration of the vegetative period of certain species and alternation of short periods of grazing with periods of vegetative rest is generally more favourable than strict or long-term protection. The dryland rangelands may keep their resilience to the negative effects of climate change once human pressures on them are controlled. A maximum of two years of rest would be enough to sustainably manage the rangelands in southern Tunisia. A deferred grazing system based on two years of rest would also resolve social barriers and increase the awareness of the agro-pastoral communities and farmers to readopt this disappeared traditional practice.

The revival of the traditional best practices under new arrangements adapted to current biophysical and socioeconomic conditions is key to building resilience and reducing the animal feed costs poor farmers are facing.
3.1.3 Soil surface scarification and reseeding with sulla (Hedysarum coronarium L.) of degraded Mediterranean semi-arid rangelands

Introduction

Alleviating rangeland degradation ecosystems and increasing their productivity are crucial for both environmental and social sustainability. Filling the gap in feed resources is a high priority to improve the livelihoods of local agro-pastoral communities. Therefore, there is an urgent need for cost-effective management actions to reverse rangeland degradation trends to improve livestock productivity and increase resilience to climate change. Rehabilitation of deteriorated pastoral ecosystems may include a wide range of interventions, such as soil erosion control, rainwater harvesting, and reseeding with rare, endangered and forage species.

Sulla (Hedysarum coronarium L.) is a legume species native to the Mediterranean basin that has high nutritive value and contains bioactive compounds, which benefit the livestock. Several studies in the northern Mediterranean region and in New Zealand have indicated that grazing sulla improves the productivity of sheep and goats and provides a suitable base for increasing the supply of animal products. Although sulla has been tested in cultivated pastures, no studies have ever explored the role and potential of sulla in rangeland rehabilitation.

A study (Slim et al. 2021) was conducted in two seasons to investigate the effects of soil surface scarification and reseeding rangelands with sulla on botanical composition, biomass production, water productivity and pastoral value in the Sbaihia community, lying in semi-arid zone of Tunisia.

Salient findings

Despite the relatively important interannual variation, the highest above ground net primary production (2,307 and 5,330 kg dry matter/ha), water productivity (9.5 and 11.8 kg DM/mm), and pastoral value (2,099 and 4,853 forage units/ha) values were recorded in the rangelands reseeded with sulla in both growing seasons. Sulla contribution in the species composition of reseeded rangelands increased from 1.7% in the first year to 2% in the second year. Although soil surface scarification increased the vegetation cover, its effect on biomass production was not significant.

Conclusion and way forward

Combined soil scarification and reseeding well-adapted native forage species has a great potential to improve productivity of semi-arid rangelands.

Reseeding in scarified soils improved the aboveground biomass production and more specifically the water use efficiency of the rehabilitated rangeland sites. Reseeding using well-adapted native legume species rich in protein, such as sulla, resulted in the enhanced nutritional value of silvopastoral systems, which suggests that these may be effective tools to provide forage as a nutrition source for livestock.
Combining soil scarification and reseeding a high nutritive forage species in degraded silvopastoral areas in the semi-arid Mediterranean rangelands would enhance the soil water interaction and increase the water use efficiency resulting in a higher aboveground biomass. Given the fact that this was a short study, during which the rainfall conditions were fluctuating, these results could only serve as an effective short-term remedy to cope with the negative effects of the ongoing climate change and to increase the resilience of the silvo pastoral communities. It is recommended that this study should be continued over the next three to five years and, if possible, duplicate it across similar environments to make solid recommendations.

3.1.4 Soil surface scarification: improving plant succession and ecosystem health toward sustainability

Introduction

Crusted or capped soils are common in arid or semi-arid degraded rangelands, either occurring naturally or because of poor management. Without measures to improve soil conditions, rangeland rehabilitation efforts often result in unacceptably low seed germination and/or seedling performance. Success rates may be improved by human intervention, using methods such as soil surface scarification to promote physical and chemical processes within the soil that enhance plant survival and growth. A study (Louhaichi. 2019) was undertaken to assess the impact of various scarification treatments on improvement of rangelands.

Salient points

One of the recommended practices for sustainable rangeland management is soil surface scarification. Applying this practice under arid climate conditions facilitates plant succession and enhances ecosystem health. Lightly breaking up the surface soil creates narrow furrows that trap moisture and improve seedbed conditions. This practice, if complemented by seeding, is a cost-effective technique for rehabilitating degraded rangelands.

Different soil surface treatments can be used to improve degraded rangelands, with surface disturbance being achieved either naturally or mechanically. These actions may have different impacts on mixed plant communities and may have a significant effect on biodiversity and rangeland structure. Natural scarification (herd effect) ideally, soil surface scarification should be achieved naturally through the action of the hooves of grazing animals. There are certain practices that can mimic predator-induced behaviour such as the use of a mobile watering facility or additional feeding and/ or mineral supplementation (for example salt in a granular form) of livestock across the landscape. Mechanical scarification (machinery), mechanical scratching or ploughing are the most common scarification techniques. The choice of field cultivator or ripper is based on how compacted the soil is, how hard the crusted layer is, and whether rocks are present. Usually, a tractor is fitted with a tool bar carrying tines, rippers, or other devices capable of disturbing the upper 5–10 cm of the crusty soil.
Conclusion

Soil scarification is recommended for bare and crusted soil. Depending on the geographic location, scarification should be implemented in advance of the early fall rainfall (usually one to two weeks before the first rain is expected). If the soil seed bank is depleted, scarification should be combined with direct seeding. Scarified areas should be protected to allow seeds to emerge and seedlings to establish. The established plants should be lightly grazed initially, with moderate grazing permitted thereafter.

Scarification improves water infiltration. It creates micro-sites for seed germination, enhances seed survival and germination, and facilitates root–soil contact. It reduces soil erosion on sites with steep slopes. It offers cost-effective opportunities for restoring degraded rangelands.

3.1.5 Benefits of short-duration, high-stocking rate opportunistic grazing on arid rangelands during favourable conditions

Introduction

Continuous grazing is widely practiced in Tunisian arid rangelands and across most drylands and deserts of the Middle East and North Africa. In the early 1990s, the Tunisian government initiated a national strategy for rangeland improvement. The strategy emphasizes grazing exclusion for three consecutive years, a practice known locally as gdel. At the end of this period, grazing is allowed with no restrictions or with some guidelines. However, these regulations created discontent among pastoral communities, mainly when local rainfall conditions result in a considerable quantity of green biomass. High stocking-
density grazing for a short period would help satisfy pastoralist concerns and achieve the government’s strategic goal.

A study (Louhaichi et al. 2021b) was conducted to assess the impact of short grazing periods with high-stocking density on vegetation during weather conditions favourable to plant growth. The study was implemented in three arid rangeland types of southern Tunisia that have been under restricted grazing for two years. Each area in the study was grazed for short periods in late May (about seven days) with a flock of 150 head of sheep. Measurements of vegetation cover, forage productivity, density and species richness were taken before and after grazing.

**Salient findings**

Perennial vegetation is more stable under grazing than annual vegetation. The presence of annual species would enhance rangeland vegetation cover and diversity and at the same time offers an opportunity for livestock to select a high-quality diet rich in protein. The suggested grazing scheme in this study produced satisfactory results compared to protected sites (livestock exclusion) or continuous grazing (control). Opportunistic grazing, applied to heterogeneous rangelands in late spring and the beginning of the annual temperature increase, encouraged animals to select annual plants due to their higher palatability, higher digestibility and water content rather than perennial species. Perennial biomass materials that die and do not fall through rapid biological decay tended to decline with increased period of placement, resulting in further oxidation to CO2 which affects photosynthetic performance negatively and may eventually cause plant death. Trampling from high-density stocking enhanced the litterfall rates and removed the oxidized plant material.

**Conclusion and way forward**

During rainy years, the vegetation response is impressive. Such positive responses do not occur every year as the most common scenario under arid conditions is recurrent drought. Therefore, it would be a lost opportunity for pastoral communities if they are not allowed to use this abundant and rich biomass. From this perspective, development agencies have been keen to revise and update projects and programs for a more flexible approach linking administration with end-user needs based on scientific evidence. These findings have implications for the health of the arid rangelands of Tunisia and the livelihoods of pastoral communities.

Properly managed, arid rangelands can provide sustainable forage resources that reduce feeding costs and enhance livestock productivity. The findings of this study may contribute to strategies for addressing the extreme climatic variations that threaten rangeland and livestock sustainability. They also offer evidence for designing approaches that could be scaled out to other regions, such as the Middle East and North Africa.
3.1.6 Rangeland biodiversity and climate variability: supporting the need for flexible grazing management

Introduction

Tunisia’s rangelands occupy approximately 5.5 million hectares, 87% of which are in arid and desert areas. They provide the main feed source of traditional livestock rearing systems and offer a range of essential products and services that support human livelihoods, such as firewood and nutritious food. In arid rangelands, plant diversity is one of the most important key functions of healthy ecosystems. Human-induced disturbances combined with recurrent droughts represent the main causes of ecosystem disequilibrium leading to threats to key plant species and consequently its floristic cortege. Resting or grazing exclusion is an effective practice widely adopted to restore degraded, arid rangelands.

A study was conducted to understand resting or grazing exclusion effect on plant diversity using the Hill’s diversity indices (Hill. 1973) during two growing seasons (2017–2019) (Louhaichi et al. 2021c). The experiment consisted of a three-level factorial design with four plant communities subjected to different resting durations (one, two and three years) compared to continuously grazed areas (control).

Salient findings

The rainfall played an important role in arid rangeland restoration. Reasonable rainfall amount and distribution led to significant increases in plant diversity for most plant communities, mainly A. henoniana and R. raetam. Under favourable conditions, one-year grazing exclusion considerably enhanced species richness and evenness diversity compared to longer resting durations under dry to average rainfall conditions.

Drawing on its own research and an extensive review of existing literature, ICARDA jointly with the OEP an agency within Tunisia’s Ministry of Agriculture, Fisheries and Water Resources, created a more flexible approach (Louhaichi et al. 2019d) to the restoration of privately owned rangeland; striking a balance between the needs of pastoral communities and those of fragile rangeland ecosystems developed a series of key indicators, shared and agreed upon with stakeholders, to guide planning and identify the conditions under which controlled rapid grazing could be permitted. In a bad or average year when precipitation and biomass production are not sufficient, no grazing is allowed in rested areas. However, in a favourable year, when plant cover exceeds 40%, at least 30% of plant species are palatable, and minimum rainfall levels reach at least 60 mm in Ramada and 80 mm in Medenine and Tataouine (areas that account for more than 75% of Tunisia’s rangelands), controlled rapid grazing can be permitted on land in the second or third year of its restoration.

Conclusion and way forward

Inappropriate grazing, which causes declines in plant diversity, alerts rangeland managers to consider suitable management changes. The decision about how long livestock grazing exclusion should last must
not be decided upfront as it depends on the climatic and the site-specific conditions. The findings of this study will have vital management implications for development agencies. Knowing that short grazing exclusion with adequate rainfall amount and distribution could be enough and offers a cost-effective technical option to ensure the sustainable restoration of arid rangeland. This flexible grazing management would also be more acceptable by the pastoral communities. Longer resting periods could have detrimental effects on arid rangeland vegetation, in addition to adding more pressure on the remaining rangeland areas open to grazing.

Maintaining rangeland plant diversity serves as an insurance policy for the survival of healthy rangelands to provide a sustainable ecosystem of goods and services. Under these conditions, it is important to consider a flexible approach to grazing management, depending on climate conditions and site specificity. This study presented an opportunity to observe the short-term changes in arid rangeland plant diversity with respect to resting duration and climate variability. Its findings have contributed to the development of sustainable rangeland management strategies across the dry areas to strengthen the resilience of the pastoral communities. In terms of implementation, OEP regional offices are responsible for deciding when controlled rapid grazing should be permitted, following field visits and measurements of biomass. Every office is expected to form a rangeland team composed of technical staff from OEP and staff from various relevant departments within Tunisia’s Ministry of Agriculture, Fisheries and Water Resources. The rangeland teams are continuously provided with capacity development opportunities, equipping them with the knowledge and skills to conduct the required measurements, decide on the optimal carrying capacity and duration of grazing, and disseminate appropriate information to inform planning.

3.1.7 Characterizing biomass yield and nutritional value of selected indigenous range species from arid Tunisia

Introduction

Rangelands of Tunisia show great indigenous species diversity with considerable potential as forage for livestock. However, information on their fodder yield and quality is scanty and restricted to a few species. A study (Louhaichi et al. 2021d) was conducted to evaluate the nutritive values of selected key perennial species based on their biomass yield, chemical composition, in vitro organic matter digestibility (IVOMD) and mineral composition. The species evaluated included four grass species (Stipa lagascae Roem. and Schult., Stipa tenacissima L., Stipagrostis plumosa (L.) Munro ex T. Anderson, and Stipagrostis pungens (Desf.) de Winter.) and eight shrub species (Anthyllis henoniana Coss. exBatt., Argyrolobium uniflorum (Deene.) Jaub. and Spach., Echichilon fruticosum Desf., Gymnocarpos decander Forssk., Helianthemum kahiricum Delile., Helianthemum lippii (L.) Dum. Cours., Plantago albicans L. and Rhanterium suaveolens Desf.).
Salient findings

Results showed that shrub species contained higher concentrations of the CP and ADL but lower fibre concentrations than grasses. The greatest concentration of CP was 135 g/kg DM for *R. suaveolens*. The shrub species *E. fruticosum, A. uniflorum, P. albicans, G. decander, R. suaveolens*, and *A. henoniana* had the highest IVOMD with over 500 g/kg DM and have the potential to supply energy to livestock.

Conclusion and way forward

The moderate to high CP and low fibre concentrations along with high IVOMD found in *E. fruticosum, A. uniflorum, P. albicans, G. decander, R. suaveolens*, and *A. henoniana* suggest that these shrub species have a higher nutritive value than the highly fibrous, low IVOMD grass species *S. lagascae, S. tenacissima, S. plumosa*, and *S. pungens*. The concentration of minerals was also high, suggesting that these plants are best for rangeland forages and for maintaining and enhancing livestock productivity.

It is recommended to reduce human disturbances through overgrazing or cultivation encroachment to preserve this native richness in their natural habitats. To ensure that plant biodiversity is maintained, it will be necessary to enforce policies that ban cultivation in these fragile ecosystems and promote sustainable grazing management.

Goats graze on *Rhanterium suaveolens* in southern Tunisia. Photo ICARDA/Mounir Louhaichi
3.2 MANAGING RANGELANDS THROUGH INTRODUCTION OF DROUGHT AND SALT-TOLERANT SPECIES

Arid and semi-arid rangelands face increasing climate variability and grazing pressure as the world’s demand for food increases. In addition to conducting research (synthesised above) to better understand the impact of climate change and grazing pressure on rangelands and their restoration using sustainable grazing practices and through characterization of native species and their introduction, ICARDA has introduced and promoted the cultivation of a number of drought-tolerant native grasses and shrubs as a crucial means of assisting rangeland rehabilitation efforts, helping to conserve rapidly-depleting water resources and maintain grazing at sustainable levels. This has resulted in a ‘win-win’ situation for rural communities and the environment. Towards this end several factsheets were developed. The focus of these factsheets has been on the introduction, establishment and maintenance of drought- and salt-tolerant species (native grasses, trees and shrubs) and their benefits mainly towards rangeland rehabilitation and livestock production. Information about these species, in brief from each of the factsheets, is presented below. For details, the readers are referred to the factsheets.

Information extracted from the factsheets has been categorised under four categories, promoting:

1) Sustainable grass and legume species
2) Sustainable shrub species
3) Sustainable tree species
4) Other species

3.2.1 Sustainable grass and legume species

Legumes fix nitrogen and improve soil health. In addition, legumes and grasses provide nutritious feed for livestock, especially in the dry and saline areas. These can form an integral part of programs targeting the rehabilitation of degraded land with moderate salinity – a condition that affects a large part of the Mediterranean region’s arid zone.

3.2.1.1 *Stipa lagascae* —A heavy, adaptable grass that provides high quality hay (Belgacem and Louhaichi. 2014a)

*Stipa lagascae* is a perennial bunchgrass that is highly palatable for livestock. This plant is found in humid to arid areas across the Mediterranean and is flexible to variations in temperature and water availability. Limited to areas with deep soils that are relatively sandy with low salinity, *Stipa lagascae* is common in sandy coastal plains, in between isohyets with 150 mm and 250 mm. This grass-type is spread throughout the Mediterranean basin – across North Africa, west Asia, and southwestern Europe – and is found in humid to arid climates.
*S. lagascae* can tolerate a wide range of temperatures and water availability and moderate salinity and can be used for rehabilitation. It is highly palatable and has high preference with livestock. It is harvested and provides high quality hay for summer feed.

Growth of this plant starts with first autumn rains. It reproduces seed at the end of the winter season with water availability and does not respond to more than 50 kg of nitrogen per hectare. Germination rate is best at 10-20°C. *S. lagascae* can form an integral part of programs targeting the rehabilitation of degraded land with moderate salinity.

### 3.2.1.2 Cenchrus ciliaris — A resilient, drought-tolerant forage species to alleviate feed shortages and feeding costs (Belgacem and Louhaichi. 2014b)

One of the most drought-tolerant of the commonly sown grasses, *Cenchrus ciliaris* (Buffel grass) occurs naturally in areas with an average annual rainfall that ranges from 100 mm to approximately 1,000 mm, but most commonly between 300-750 mm. Buffel grass often occurs in the wild on sandy soils, but is also well adapted to deep, freely draining sandy loam, loam, clay loam and red earth soils.

Buffel grass has a distributional range in areas with average annual temperatures of between 12-28°C and performs best in areas with mean temperatures that exceed 5°C. Optimal growth is incremental with an increase in temperature - and is reached at 35°C. The plant is found in areas with full light and is intolerant of shade. Some varieties are better adapted to cooler environments than others. This plant requires good fertility, particularly with respect to nitrogen, phosphorous and calcium.

It establishes by direct seeding, seedlings or cuttings. The plant is slow to establish and therefore grazing may need to be delayed by 4-6 months and sowing by 9-12 months, depending on conditions. It requires fertilization after cutting or grazing. Once established, cutting or grazing can be done frequently, every eight weeks, since quality declines with age.

This grass offers several benefits: drought-tolerance —ability to survive in areas with annual rainfall ranging from 100-1000 mm; ability to endure up to five days of flooding with negligible effects; wide distributional range —occurring in areas with average annual temperatures between 12-28°C and reasonably high crude protein, about 9.6 % with CP digestibility of 50-60%.

Buffel grass is a resilient, drought-tolerant forage species, with good nutritional value for livestock. It has potential to alleviate feed shortages and feeding costs in the dry areas of the world.

### 3.2.1.3 Cenchrus setigerus — A resilient, drought-tolerant perennial grass for pastures in hot, dry areas (Kumawat et al. 2015)

*Cenchrus setigerus*, commonly known as Birdwood grass, is one of the most drought-tolerant perennial grasses. Native to east Africa and western Asia between latitudes 30⁰N and 30⁰S, this grass occurs naturally in areas with average rainfall between 125-1250 mm. The tufted grass is very resilient,
withstanding low and sporadic rainfall, long dry seasons, strong winds, high temperatures, frost, erosion, nutrient-poor soils and salinity.

The grass is most nutritious at the pre-flowering stage when average values are 18.6% crude protein, 28.3% crude fibre, 11.9% ash, 1.9% ether extract and 39.3% nitrogen free extract. In dry matter, digestibility and energy digestibility average 57.4% and 54.9% respectively.

Pastures can be established by direct seeding, by planting seedlings or by planting root slips. For irrigated areas, pelleted seed by mixing with silt and cow dung germinates more successfully. It is suggested to remove weeds from pastures sown with seed after 3–4 weeks. Grazing should be started 4–6 months or, in harsh conditions, 9–12 months after sowing. Cut grass 5 cm above ground level when 15% is in flower for maximum yield is obtained at 15% flower stage. Pastures should be allowed to seed every 2–3 years to develop dense growth. Application of 40 kg/ha nitrogen or 20 kg/ha phosphorus increases yields by 15–38%.

It is a drought-tolerant grass and is also resistant to heat and cold. It grows in a range of soils, from sandy, sandy loam, stony, murrum (calcium carbonate) to alkaline. It can be cut for feed, hay or silage making three to four times a year. On average 1–1.5 t/ha dry forage is produced. The forage is highly nutritious, especially beneficial for milk producing animals.

### 3.2.1.4 *Stipagrostis pungens* (Desf.) De Winter — A xerophytic quicksand- and dune-fixing species adapted to sandy deserts (Gamoun and Louhaichi. 2018)

*Stipagrostis pungens* is a perennial grass species which belongs to the Poaceae family. It is usually found with several erect culms, grows up to 1.5 m in height, and forms substantial tufts. It is a tall stiff grass with pungent leaves, and a C4 grass with sclerophyllous, spine-tipped, in rolled leaves, with sunken stomata. The root system extends laterally for a radius of 20 m or more. The roots are covered throughout their length by a sandy sheath, which is penetrated by the root hairs that occur throughout the entire length of the sheath. The piliferous layer of the root cap acts as a mucilage-secreting gland, the action of the mucilage easing the passage of the root tip through the grains of sand. The mucilage has high absorptive properties, concentrating any soil moisture around the sheath, from which it may be taken up by the root hairs.

### 3.2.1.5 *Hedysarum coronarium* L. — A biennial herbaceous legume used for forage (Louhaichi et al. 2018d)

*Sulla* (*Hedysarum coronarium* L.) is deep rooted and drought resistant. This species native to the Mediterranean is effective in biological fixation of sloping land and improving organo-mineral soil fertility and yields and protein value of cereals. It is a biennial or short-lived perennial with semi-erect to erect growth, height of 0.3–2 m, strongly rooted, with root depth exceeding 2 m and numerous secondary roots.
3.2.1.6 *Lasiurus sindicus* Henrard — A promising, drought-tolerant, tussocky perennial grass suitable for pasture development in desert areas (Kumawat et al. 2019a)

Sewan grass (*Lasiurus sindicus*), popularly known as the king of the desert, is remarkably well adapted to the desert. High water-use efficiency enables this native grass to maximize production even in areas of scanty rainfall (100 mm annually) when little water is available. The crown (rhizome), in which food (starch and sucrose) is stored and protected by scaly layers, is highly compressed, which allows the plant to remain dormant for years without moisture. This factsheet describes the plant benefits and management.

3.2.1.7 *Stipa tenacissima* — A nurse species to initiate the process of ecosystem restoration (Louhaichi and Gamoun. 2017)

*Stipa tenacissima* is a long-lived perennial grass that dominates the Mediterranean Basin steppe, covering more than 2.8 million ha and growing in almost all geomorphological units. The plant seems to prefer calcareous soils that are shallow and permeable with a very sandy texture. It does not adapt well to soils with gypsum, salt, clay or loam content. Besides this, it is distributed within a wide range of bioclimates with great tolerance to temperature variations. Its optimal bioclimatic stages are arid superior and semi-arid lower.

3.2.1.8 *Lathyrus sativus* L. — A Neolithic dual purpose annual legume grown for its seeds for human consumption, and fodder for livestock feeding (Louhaichi and Hassan. 2020)

*Lathyrus sativus* (Grass pea) is a cool season legume species that can be grown in non-tropical dry areas with 200–350 mm average annual rainfall. Although it is tolerant to drought stress, it can withstand flooding and survive under excessive rainfall. The origin of grass pea is unknown; however, it is thought to centre on southwest and central Asia or the Balkan peninsula. It is a multipurpose crop for grain, feed, vegetables and straw that improves soil fertility through atmospheric nitrogen fixation.

3.2.1.9 *Stipa parviflora* Desf. — A drought tolerant, palatable, perennial grass species (Louhaichi and Gamoun. 2021a)

*Stipa parviflora*, or small-flowered feather grass, is a densely caespitose perennial grass species belonging to the Poaceae family, usually with several erect culms and growing up to 70 cm high. It is a xerophyte common in arid and semiarid flats and plains and on hill slopes and dry mountains. It is highly palatable and highly nutritious. It is well adapted to dry conditions and to a wide range of soil textures. It is useful for erosion control.

3.2.1.10 *Astragalus cicer* L. excellent perennial forage legume resistant to grazing (Louhaichi et al. 2021e)

*Astragalus cicer* has great potential to provide forage because of its strong perenniality, winter hardiness, drought, moderately salt and cold tolerant, considerable resistance to some insects that attack other species of forage legumes, non-bloating traits, relatively high forage yield, nitrogen-fixing ability and
compatibility with cool-season perennial grasses. *A. cicer* is an ideal species for long-term pastures and disturbed lands. About 50% of its total yield is produced in the first growth period of the season. *A. cicer* is a very competitive legume widely recommended as a component of mixtures for the revegetation of disturbed lands, and it is also one of the most winter-hardy species of cultivated forage legumes. It is used for soil conservation through reducing erosion. It is an excellent livestock feed and has high protein content.

3.2.1.11 *Hedysarum carnosum* Desf. – An important halophytic pastoral legume that tolerates stressful conditions in arid and semi-arid rangelands (Louhaichi et al. 2021f)

Dryland pastoral landscapes are characterized by unpredictable climate change and frequent ecological disasters such as drought and livestock diseases. Facing such constraints, forage legumes – including the genus *Hedysarum* (sulla) – have many advantages for use in improvement of rangelands and forage production.

*Sulla carnosa* or sulla of Sousse (*Hedysarum carnosum* Desf.) is a halophytic pastoral legume that tolerates stressful conditions (it tolerates up to 18 g salt per L). Indeed, it can remove salt from salt-contaminated soil. This plant can maintain its maximum biomass production (6-10 tons DM/year) potential mainly due to the maintenance of Na+ concentration and water content. It is adapted to regions with cool winters. In addition, it can absorb the major nutrients despite the presence of salt in soil solution. It is highly palatable to ruminants.
3.2.1.12 *Lotus creticus* L. – A high forage quality and greatly salinity legume (Tlili and Louhaichi. 2021)

*Lotus creticus* is a perennial species. It is among recommended species on restoration of marginal and degraded lands in arid areas. It is used in sand dune stabilization. Being legume, it fixes nitrogen improves soil fertility. It can grow in poor soils, which can thrive under stressful conditions (salinity and drought) and even waterlogged soils. It prefers sandy soils with coarse sand.

It is easy and quick to establish. This species is highly palatable and is a fodder plant used in reclamation of saline soils. It is adapted to salinity, drought, temperature and severe winds. It is adapted to saline-alkaline, rocky and sandy soils. It is used for soil conservation purposes. Its seeds have high protein levels and antioxidants.

3.2.2 Sustainable shrub species

Shrub plantation contributes to ecological sustainability of rangelands while aiming towards livelihood improvement. To alleviate the spread of rangeland degradation, planting shrubs provides a large amount of fodder for livestock, combats desertification and plays a key role in natural resource conservation.

3.2.2.1 *Atriplex halimus* – mitigating highly saline soils (Abu-Zanat and Louhaichi. 2014)

One of the most planted shrubs in the Mediterranean, *Atriplex halimus* is known for its remediation of degraded rangelands and salt-affected areas. It is commonly used as a forage plant for sheep and goats in arid areas and contributes significantly to the feed calendar when herbage availability is low. It is the only green, protein-rich forage available during late summer and early fall – when it is needed for the nourishment of pregnant and early-lactating ewes and does.

*A. halimus* is tolerant to drought, salinity and alkaline soils. It is a good plant for phytoremediation of highly saline soils. It can grow in shallow soils, on steep slopes and in depressions. It produces a lot of seed after two growing seasons and self reproduces. It flowers from June to September and seed mature in November-December.

*A. halimus* is the most planted native species in the Mediterranean region and is established by either direct seeding or containerized seedlings, depending on the distribution and amount of rainfall. In areas receiving 150-250 mm of annual rainfall, direct seeding in wide contour furrows or strips is recommended. Seeds should be cleaned, dried, and treated with fungicides. Contour furrows or strips should be 50-100 cm in width. In areas with low and erratic rainfall receiving 100-150 mm annually, containerized seedlings of five to six months should be transplanted. For vigorous growth it is recommended to transplant into contour ridges or bunds. They assist in harvesting and catching water for greater plant growth. Significant amounts of seed are produced after two growing seasons, following establishment. Seeds are dropped around the mother plants and germinate immediately after good rainfall. With enough water, these small seedlings can grow into mature plants further promoting self-regeneration.
3.2.2.2 *Periploca laevigata* – A soil stabilizing shrub that can grow in poor soils (Neffati and Louhaichi. 2014b)

*Periploca laevigata* is an important shrub for grazing in the dry season. Although it contains tannins, it is palatable and is grazed mainly by camels, sheep and goats. As this plant can grow in dry and rocky conditions in the poorest of soils it has good potential for increasing forage in dry areas as well as reducing erosion. The plant is also known for its many healing properties. *P. laevigata* is promoted in many development projects - linked to soil conservation and sustainable water and forage usage across North Africa and the Middle East. This plant is found in places with hot temperate winters and mainly colonizes rocky substrates - it can grow in many different types of soil and is known to be found in the driest and poorest of soils. What makes this plant unique is that it is often found on steep slopes with scraps of calcareous crust, a condition that cannot support many plant species. It can grow up to three meters tall and its root system develops according to soil depth. The leaves are evergreen but occasionally become deciduous under water stress. As a result, the plant not only improves forage availability but also helps to stabilize soil. *P. laevigata*’s distribution ranges from sub humid to Saharan climates, as well as warm and temperate microclimates.

For effective establishment and management, mature seeds should be harvested from May to June (when the leaf colour changes), ideally by hand and a grazing rest period should be implemented. The plant has a high reproductive capacity, but seeds are not produced until the plant reaches two to three years of maturity. The seeds should be air dried and sown in October at 25-35°C.

It provides several benefits. It can grow in rocky soil with calcareous substrate. It is resilient, with well-developed root systems and is very drought tolerant. It has multiple medicinal uses. It produces many seeds and stabilizes soil. It is a good feed for camel, goats, and sheep. For efficient use, mix this shrub with feed because it is rich in tannins.

3.2.2.3 A sustainable shrub species – *Retama raetam* (Louhaichi and Neffati. 2014a)

*Retama raetam* is a resilient, pioneer plant for rangeland rehabilitation and stable ecosystems. It is noted as an important multi-purpose species in need of conservation. It is a drought-tolerant legume species native to the Mediterranean, which is beneficial for dune stabilization and rangeland rehabilitation. Retama can also establish itself on nutrient-poor to fertile well-drained soils, and plays a prominent role in rehabilitation efforts, acting as a pioneer plant in the ecological succession of barren lands. It can produce a ‘scrub layer’ with smaller plants (providing there is sufficient water) and has an ability to fixate nitrogen, helping to improve soil fertility and create microclimates for future plant establishment.

Effective propagation depends upon a combination of factors, including water availability, plant age for seed harvesting and seed scarification for increased germination. Flower and seed creation takes two years to establish. Each plant produces hundreds of seed pods and up to a thousand seed pods on larger plants. Given that seeds are consumed by many animals, fencing is recommended for seed production. As a result of the hard coating and low germination rate (6%), scarification is also recommended, an action
that increases the germination rate to 70%. It is further recommended that seeds are harvested in May-June when mature pods are easily detached from plants and fall to the ground.

Aside from serving as a pioneer plant in the rehabilitation efforts of barren lands the leaves and seeds can be used for grazing. This shrub can fix sand dunes and stabilize ecosystems. It can survive in dry and harsh conditions. It is resilient, drought-tolerant legume species with well-developed root system. It produces a significant number of seeds and the seeds remain viable in soil for long periods.

3.2.2.4 *Calligonum comosum* – the multipurpose sand dune stabilizer (Louhaichi and Neffati. 2014b)

*Calligonum comosum* is known as Fire Bush or Arta. It is an excellent pastoral species for fixing soil and providing a source of protein for livestock. Its wood is highly prized as fuel, as it burns smokeless. It grows in coarse sandy desert soils and is used for grazing, firewood, sand dune fixation, and pasture rehabilitation. It plays a vital role in the fight against desertification. In addition to being cultivated around desert plantations and used as a wind break, it is also utilised for medicinal purposes and human consumption.

For effective management of this shrub, harvest seeds by shaking the female plant and plant the seeds deep in the soil in the field. Seeds germinate best in the dark, at 20°C and declines as temperature increases.

*C. comosum* can survive in dry and harsh conditions. The shrub has many medicinal uses and the young shoots are consumed by humans and livestock. It contains 68.3% total digestible nutrients and is a good forage for camels. In addition, it provides smokeless firewood used for tanning hides.

3.2.2.5 *Atriplex nummularia* – Highly drought and salt tolerant shrub, well-suited for rangeland rehabilitation and for providing quality fodder for livestock when herbage availability is low (Clifton et al. 2017)

*Atriplex nummularia* is a key feed resource in times when other feed is not available. This plant is grown in arid areas all over the world and is often promoted to improve forage availability. As a result, this plant is easily accessible in many areas. Improved rangelands with this plant provide an economic alternative especially during the dry season. This plant is a good choice for sites high in salinity. It can grow in saline environments up to 300 m but the growth decreases in higher saline environments.

Establishing *A. nummularia* from seed is difficult as the fruit has germination inhibiting chemicals. However, establishing from vegetative cuttings can create plants of one sex. If established from seed *A. nummularia* can have male, female or bisexual plants. It is recommended to place 50 viable seeds per placement to improve success. Median establishment rates were higher for planting seedlings (90%), than direct seeding with purpose-built niche seeders (18%). Planting seedlings can have many different densities or layouts. Grazing for short period at high stocking rates and allowing for six months rest is
suggested. Grazing the plant every year and pruning it every other year to keep it within the reach of grazing is recommended.

Leaves have a higher nutritive value than twigs. The high amount of salt limits its potential. When tested in north-eastern Jordan, crude protein of leaves reached a maximum of 17.7% in the twigs and 21.3% in the leaves in February. Crude protein declined from June to December. This feed can carry livestock through the dry season. But water intake of livestock increases two to three times because it is high in salt. It is adequate in crude protein content but low in energy. It is suggested to supplement with grain or good quality hay for optimal animal performance. It is known as one of the most productive plants for wool production.

3.2.2.6 Atriplex leucoclada – mitigating highly saline soils (Louhaichi et al. 2017)

*Atriplex leucoclada* is one of the most planted native *Atriplex* species in degraded rangelands of West Asia. It is a drought, salt and high heat-tolerant shrub, and yielding low to high edible biomass. It is a biennial plant and its height usually ranges between 30-100 cm. Its stems are prostrate to erect and it has bluish-grey leaves which have high protein content (12-22%). Due to its high water-use efficiency and ability to produce high dry matter quantities, it regenerates well after grazing/browsing. It occupies sandy soils, effectively stabilizing severely disturbed rangelands and controlling erosion. It is characterized by its short growing season and has a limited grazing period from April to June, after which it reduces its productivity levels.

The most used propagation technique for *A. leucoclada* is by transplanting seedlings because its dormancy reduces the effectiveness of revegetation from seeds. Planting density affects its mean yield per plant, which tends to decrease as densities increase from 2,500 to 10,000 plants/ha. It is well adapted to desert environments, with thick and almost cartilaginous leaves covered by dense trichomes and by salt crystals that completely cover the leaf blade. It flowers between March and October and its seeds mature thereafter (between September and November). *A. leucoclada* can grow and reproduce under rainfall conditions ranging between 100-300 mm/year, with yields varying from 1,000-3,000 kg of dry matter/ha per year.

For efficient establishment and management, clean, dry and treat seeds with fungicides for storage, treat seeds to break dormancy e.g. scarification and give a minimum of three months between grazing/browsing events.

The plant exhibits high forage value and it is one of the best range plants from the chenopodiaceous family. It is grazed by all livestock classes (camel and small ruminants). Livestock especially consume its dry and green forage during the dry season in arid rangelands. It has a high nutritional value and the ability to be grazed in summer. It is characterized by relatively high digestible protein, which is comparable to that of Alfalfa. Appropriate management of this shrub species requires a rest period from grazing and pruning at 25-50 cm above the soil. This allows the fewer leaves left on the shrub to grow on the higher
parts of the plant, thus reducing moisture loss through transpiration. *Atriplex leucoclada* has a high ability to absorb nitrogen from the soil and can benefit from the action of nitrogen-fixing microorganisms.

*Atriplex leucoclada* is one such native biennial and palatable halophyte species in the Mediterranean region. Due to its easy and rapid establishment in both saline and degraded rangelands, it is being used as a source of feed, especially in autumn and winter, when forage for grazing is very low.

3.2.2.7 *Rhanterium suaveolens* Desf – A keystone species critical to rangeland structure and functioning (Louhaichi and Gamoun. 2018)

*Rhanterium suaveolens* is a desert plant endemic to North Africa and is best developed in parts of the sandy plains of the northern Sahara characterized by deep sierozem soils. In arid rangelands, the production of *R. suaveolens* can represent a great part of fodder production. It is especially valuable when accompanied by good rains, and is preferentially consumed during summer grazing, when it is among the preferred destinations of many herds of sheep, goats and camels.

*R. suaveolens* can tolerate sand accumulation and thereby fix drifting sand. It tolerates multiple stress and disturbances and promotes rangeland diversity. It is critical to ecosystem structure and functioning. After rainfall, *R. suaveolens* produces new leaves quickly. In a few months, the branches and newly formed leaves become vigorous. It is a long-lived species and can tolerate multiple stresses and disturbances.

The plant does not tolerate water deficit, and the germination rate of seeds is low. The optimum temperature for germination is typically higher than 20°C. The seeds have been found to be negatively photosensitive, with their germination capacity and speed increasing in darkness. The favoured seeding depth is 8 cm. Germination is strongly hampered by the presence of integumentary inhibitory substances, which need to be washed out by rains. All these characteristics slow down the seedling establishment of *R. suaveolens*, with particularly favourable conditions being necessary for germination.

3.2.2.8 Promoting native shrub species: *Ziziphus nummularia* – A promising forage shrub for silvopasture in arid and semi-arid ecosystems (Kumawat et al. 2019b)

*Ziziphus nummularia* is one such important shrub species of arid and semi-arid tracts. Continuing to supply foliage over a long time, it plays a vital role in the economy of dryland peoples. It is a multipurpose shrub, thorny, medium-sized straggling shrub. This factsheet describes the plant benefits and management.

3.2.2.9 *Bassia prostrata* (L.) – A resilient drought and salt tolerant shrub use for rangeland improvement and for provision of quality fodder for livestock (Louhaichi and Toderich. 2018)

*Bassia prostrata* is a perennial chenopod that grows in the arid and semi-arid areas of Eurasia and the Mediterranean. It occurs naturally in saline, sandy, rocky and poor soils of central Asia. It is a long lived (life span 7-12 years) semi-evergreen semishrub of 0.3-1 m tall. It is a drought and medium salt tolerant C4 species. Above ground biomass and seeds are a source of protein that can improve animal quality. As a result it is popularly used in rangeland rehabilitation efforts and is thought to have potential for
reclamation of salt-affected soils. It also has an extensive fibrous root system which improves soil stability. While further studies are still lacking, optimal salt concentrations of 150 milli-molar (mM) of salt have been reported. Concentrations of 200 mM of salt lead to a significant decrease in growth. It can sustain heavy grazing.

3.2.2.10 Rhus tripartita (Ucria) Grande – A rare and endangered species with great ecological value (Gamoun and Louhaichi. 2019b)

*Rhus tripartita*, an endangered shrub species, is distributed in isolated populations within areas that have an altitude of 10–500 m and receive 100–600 mm of rainfall each year. It is usually found on calcareous soils, but it can grow in a variety of types of soil from deep clay-textured soil to fissures in hard limestone, dolomite rock or granite where soil has accumulated. Young trees should be protected from grazing and can then reach heights of more than 3 m. Heavy grazing is detrimental to the plant reproduction. It is drought-tolerant and can be used successfully in the rehabilitation of degraded arid environments. It adapts well to high salinity. It is a multipurpose species with great medicinal and aromatic features and is used for tanning of leather.

3.2.2.11 Artemisia herba-alba Asso – A drought tolerant subshrub well known as an aromatic and medicinal species (Louhaichi and Gamoun. 2019)

*Artemisia herba-alba* is a dwarf shrub which grows rapidly in dry and warm climates. It is found on the steppes of North Africa, the Middle East and southwestern Europe. The plant is also common in sandy or silty soils and hillsides, from the upper semi-arid to the lower Sahara. It is used for rehabilitation of degraded arid rangelands. It tolerates drought stress well. It is an important medicinal species and has an intense fragrance.

3.2.2.12 Nitraria retusa (Forssk.) Aschers – An important sand stabilizer shrub for saline deserts (Gamoun and Louhaichi. 2019b)

*Nitraria retusa*, also known as *Ghordaq* or *Sahanoon*, is one of the leading halophyte perennial shrubs belonging to the Nitrariaceae family where it was separated from the Zygophyllaceae family. This species is a salt-tolerant and drought resistant shrub which grows in steppes, deserts and saline soils. It is tolerant to frost and diseases and has a continuous range of distribution. It is Saharo-Arabian, with some trends towards Sudanian territories, and it forms almost pure stands, mainly on the periphery of marshes. It is palatable for grazing animals and is used as a traditional medicinal plant. It easily adapts to the harsh environmental conditions of desert areas.
3.2.2.13 *Salsola vermiculata* L. – A highly palatable shrub for silvopasture in arid and semi-arid ecosystems (Abu-Zanat et al. 2020)

*Salsola vermiculata* is tolerant to low annual rainfall and poor soils and has become an important perennial species in arid and semi-arid areas of the Mediterranean, the Middle East, and North Africa. Seeds germinate rapidly with adequate soil. It can also tolerate moderate salinity and is highly palatable to animals. It is a good source of protein for livestock and is a prolific seed producer.

3.2.2.14 *Gymnocarpos decander* Forssk. – A highly palatable species facilitating the establishment of annuals vegetation under arid climate (Gamoun and Louhaichi. 2020a)

*Gymnocarpos decander* is a perennial, cushion shaped dwarf shrub from the family of Caryophyllaceae. It grows in rocky and stony soils without sand and on limestone cliffs up to an altitude of around 1,500 m and avoids direct salt influence and sandy soils. It is highly resistant to harsh climatic conditions, highly resistant to grazing and highly palatable. It is rich in calcium and has crude protein content of around 10%. It may be used to reduce desertification process.

3.2.2.15 *Plantago albicans* L. – A perennial herbaceous species that is highly palatable and widely distributed across the Mediterranean region (Gamoun and Louhaichi. 2020b)

*Plantago albicans* L. is a rosette, perennial, hemicryptophyte herbaceous plant belonging to the Plantaginaceae family. *Plantago albicans* is widely distributed in the temperate regions throughout the Mediterranean region and southwestern Asia to Iran, along a wide altitudinal gradient of 0–1,300 m asl. Known as Yanam, Plantago albicans grows on wastelands, slopes, stony land and on dry and sun exposed
soils. It is tolerant to osmotic and salt stresses. It is a highly palatable species and has a very high-quality forage. It is extensively used in traditional and modern medicinal applications.

3.2.2.16 *Rosmarinus officinalis* – A multi-purpose shrub species; a medicinal, aromatic, and ornamental plant (Louhaichi and Gamoun. 2020)

*Rosmarinus officinalis* L., or rosemary plant, known as *Iklil* in classical Arabic, belongs to the Lamiaceae family. Rosemary is a native plant of the arid regions of the Mediterranean. However, this plant is cultivated in warm, dry climates throughout the world and prefers calcareous, well-drained soils. Rosemary has been commonly exploited for a long time for the quality of its essential oil, which is widely used in cosmetics and in some pharmaceutical industries. The highest-quality essential oil is obtained from the leaves. This oil can be used for various applications such as adding aroma to food. It is also widely used culinary spice.

3.2.2.17 *Astragalus hamosus* L. – A legume species for revegetating arid degraded rangelands (Louhaichi et al. 2021g)

*Astragalus hamosus*, a small shrub, produces high quality forage and fixes nitrogen, which helps in maintaining productivity of rangelands. It is a hardy drought-tolerant plant. It provides a good quality forage, especially for sheep and is adapted to heavy grazing. It is potentially useful for soil conservation. It is also one of the most important medicinal plants and is used as a diuretic, demulcent, emollient, laxative, antioxidant, anti-inflammatory and in treating ulcers.

3.2.2.18 *Aloe vera* (L.) Burm. f. – A multipurpose plant for arid climates and poor soils (Hamdeni et al. 2021)

*Aloe vera* is a spiky cactus-like xerophyte, a succulent plant (shrub) with Crassulacean Acid Metabolism (CAM) photosynthesis. It is a clump-forming perennial with thick fibrous roots and produces large basal leaves, usually 12–16 per plant, weighing up to 1.5 kg when mature. The leaves are covered by a thick cuticle and grey-greenish in colour. Aloe vera can be grown in dry climatic conditions in poor soils. It requires sandy loam soil with adequate drainage and a temperature of around 20–22°C. It is suitable for arid and semiarid regions and tends to tolerate high pH levels of up to 8.5. Its water-soluble component contains several nutritive compounds: polysaccharides, vitamins, enzymes, amino acids, minerals and trace elements.
3.2.2.19 *Artemisia campestris* L. – An ecologically important herb (Gamoun and Louhaichi. 2021a)

*Artemisia campestris*, commonly known as Tgouft, is a perennial spontaneous aromatic herb belonging to Asteraceae family. It is widespread in Northern Africa and other similar Mediterranean agroecological zones and is commonly used as an herbal medicine. *Artemisia campestris* is described as a ‘pioneer’ and a ‘climax’ species. Tolerate disturbances and occurs on ‘waste’ areas, roadsides, active sand dunes, grazed sites, and old fields. It has a marked ecological plasticity; however, the most appropriate conditions for this species occur in semi-arid climates. It has several allopathic and antifungal constituents.

3.2.2.20 *Thymelaea hirsuta* (L.) Endl. – A herb with excellent medicinal benefits but classified as a toxic herb (Gamoun and Louhaichi. 2021b)

*Thymelaea hirsuta* is a perennial shrub (phanerophyte) known locally by the Arabic name of *mithnan* or *mitnan*, which means rope or sinew. It grows on sandy and stony steppe and desert areas, dry slopes of hills, sandy coasts, saline habitats and sparse forests around the Mediterranean. It is a xerophytic, evergreen, microphyllous, heavily branched shrub, growing up to 2 m tall, with roots wide and extending to a depth of up to 3.5 m, helping the plant obtain water in harsh desert environments. It is drought tolerant and used for dune stabilization. It is used in manufacture of high-quality paper. It contains excellent fibres from which fine strings, thick cords and ropes may be made.

3.2.2.21 *Peganum harmala* L. – A noxious invasive perennial herb species, toxic to livestock but medicinally important (Gamoun and Louhaichi. 2021c)

*Peganum harmala*, commonly known as African rue, Syrian rue and wild rue is an herbaceous perennial flowering plant that is widely distributed in central Asia, North Africa, and the Middle East. It is nitratophilous, occurs mainly in dry areas and saline waste areas, but is also common along roadsides, in degraded pastures and near camping sites, field edges and watering facilities. It prefers disturbed environments. It can grow in many soil types, including alkaline soils and those with high salinity. It is
extremely drought tolerant and exhibits ‘drought evader’ growth characteristics. It has been used in traditional medicine. It is used as an indicator species for degraded rangelands due to overgrazing or from agricultural activities. It is commonly used as an insecticide.

3.2.2.22 Atriplex mollis Desf. – A halophyte drought tolerant shrub

Atriplex mollis is one of the species especially recommended for arid zone restoration projects, with its use associated with improving physical characteristics of soil and providing environmental protection by controlling runoff and reducing soil erosion on slopes. A. mollis plant litter can modify the topsoil salinity, along with other soil properties such as infiltration. In other areas, this species may also be used for wildfire prevention purposes, with the high salt concentration found in its leaves increasing their moisture content, makes it behave as a fire retardant in the event of wildfire. A. mollis is a highly palatable and a highly salt-tolerant plant species.

The distribution of the genus Atriplex in arid and semiarid areas and its abiotic stress tolerance combined with the utility of Atriplex species for restoration, remediation and forage for livestock have helped these plants to rank among the most widely studied native stress-tolerant species.

3.2.2.23 Medicago arborea L. – An important perennial woody leguminous shrub with great forage and nitrogen-fixing potential (Louhaichi et al. 2021h)

Medicago arborea is highly recommended as a model legume for revegetation, regeneration, and the biological reactivation of semi-arid degraded ecosystems. It also provides a source of fodder for livestock and wildlife. M. arborea is a highly palatable shrub that can act as a nutritious and high-quality forage species with 15-19% crude protein and 65% in vitro organic matter digestibility. It provides a valuable browsing resource while also preventing soil erosion by increasing soil stability through organic matter
accumulation. As a result, it improves land use in areas in danger of progressive abandonment and degradation, while also improving soil fertility by transferring nitrogen to the soil plant system and depositing plant litter. The shrub is used to improve semi-arid rangeland which are characterized by low production.

### 3.2.3 Sustainable tree species

Legume trees are gaining considerable interest in agroforestry in the arid and Mediterranean regions because they play a significant role in both agricultural and natural ecosystems by having a determinant role on the nitrogen cycle, being an alternative feed resource for livestock and rehabilitating degraded ecosystems.

#### 3.2.3.1 Acacia modesta – A frost-resistant and drought-tolerant tree ideal for alleviating feed shortages and feeding costs (Louhaichi et al. 2015a)

*Acacia modesta*, commonly known as Phulai, is a member of the family Fabaceae (also called Leguminosae) and sub-family Mimosaceae. It is a deciduous, slow-growing small tree with thorny young shoots and dark brown and black wood. In natural forests, the trees have a 30-year felling cycle and 60-year rotation period on reaching 7 m height and 20 cm diameter. This drought-tolerant tree is typically found in Pakistan, India and Afghanistan, where it can grow in areas with a yearly rainfall between 250-1300 mm.

*A. modesta* can be propagated through seed. Clean seed must be stored in a cool dry place, ideally in airtight containers to avoid excessive losses in germination rates. It can safely be kept in these conditions for up to three years. Fresh seeds can be sown as they are, but if using older seeds a pre-treatment to facilitate germination is recommended. This may involve nicking the seeds to remove the outer coat and/or soaking in water for 24 hours or sulfuric acid for 5 to 15 minutes. Treated seeds should be planted immediately. For planting, the best method is to sow seeds in nursery conditions in polythene tubes containing a 2:1 silt and manure mixture. Seeds start to germinate within one to two weeks but should only be transplanted to the field after 9-12 months. Very young plants need to be protected from grazing. Forage production can be maximized by managing forest in a coppice system.

It is a drought-tolerant tree, moderately resistant to frost. It grows in many different soils, including dry shallow soils. It is adapted to a wide range of temperatures, from -5°C to 40°C. It provides a highly nutritious fodder for goats and camels (young shoots have 16% CP), with digestibility value ranging between 60-70%. So far, no insect or disease problems have been identified, granting this tree great potential to be used in reforestation in dry and arid locations. The plant is also popular in herbal medicines, including those for the treatment of muscular conditions, back pain, and stomach problems. Other uses include fuel, wood, apiculture, gum and soil conservation.

#### 3.2.3.2 Leucaena leucocephala – A versatile tree producing nutritious fodder for ruminants (Louhaichi et al. 2015b)
Originally from Central America, the tree *Leucaena leucocephala* has been naturalized in many areas throughout tropical and sub-tropical Africa and Asia, including the Pothwar region in Pakistan. Such wide distribution has given rise to many popular names including Iple, and Guage in its native Mexico. Fast-growing *L. leucocephala* is well adapted to hot and humid climates, thriving in temperatures between 25°C and 30°C and yearly rainfall between 650-1500 mm.

Despite its preference for humid and sub-humid climates, *L. leucocephala* is very tolerant of periods of drought. Even during establishment, young seedlings can survive long periods of dry conditions. *L. leucocephala* is used mostly as forage for livestock, both after cutting for use as fodder, or direct grazing, typically planted in hedgerows with grass. It responds well to a coppice system and branches vigorously.

For effective establishment, seeds must be scarified before planting to break the outer waxy layer, either mechanically or by dipping in hot water. The seeds can be transplanted as bare-rooted plants, or as seedlings at three to four months old. Cuttings of foliage can be obtained at 6–12-week intervals during the growing season.

It is a drought-tolerant tree and can grow in a wide variety of soils, except if waterlogged or subject to flooding. The annual dry matter yields can reach up to 15 tonnes/ha. It provides a highly nutritious (high crude protein content of > 17% and digestibility between 55% and 70%) and palatable forage for ruminants. On average, livestock can gain 700–850 g/day when fed on this forage. The forage is rich in mimosine which can elicit adverse effects, and therefore the level of this tree foliage in the diet should not exceed 30% on dry matter basis.

3.2.3.3 *Acacia cyanophylla* – A multipurpose tree mainly used for reforestation of degraded landscapes (Jarradi and Louhaichi. 2017)

*Acacia cyanophylla* (also known as Acacia saligna) is one of three priority multipurpose tree species for arid and semi-arid zones. It is well adapted to semi-arid and sub-humid regions and is a high potential species for use in restoration. Its cultivation could benefit livestock farmers as a strategic fodder reserve during the dry season because its protein levels are high (15-21%). It is appreciated for its use as a fence, windbreak and visual screen as well as for shade and shelter. It is also used for beautification projects and for combating desertification. Its leaves, seeds, and pods can be used as a livestock feed resource, while its wood is used for firewood, timber and charcoal production.

*A. cyanophylla* produces a large quantity of seeds, which should be stored in a cool dry place. The most used propagation technique is by seed, which requires seedling management in nurseries. It germinates well under direct seeding. It grows well on deep sandyloam alluvia soils receiving an average of 150 mm annual precipitation. *A. cyanophylla* can regrow new shoots after being harvested (rotation of four years) and it needs to be protected from overgrazing. Its use of atmospheric nitrogen to enrich the soil makes it a pioneer species capable of colonizing nitrogen poor soils and barren sites, and thereby playing a particularly important role during ecological succession, as it also rapidly establishes cover following major natural disturbances such as a fire.
At maturity stage, fodder biomass production can reach up to 3.5 t DM/ha/year. The fodder biomass production can be optimized by regular and annual harvesting. Its fodder should not be used as a sole diet for animals because of its high tannin content. It is one of the potential species for restoring degraded rangelands.

3.2.3.4 *Pistacia lentiscus* L. - A multipurpose tree species that withstands drought and protects the soil (Slim et al. 2018)

*Pistacia lentiscus* (Lentisk) is an evergreen tree that is a hardy, drought tolerant plant, which can be found in scrubland. Its ecological value is related to the ready production of new shoots following fire injury or cutting. The species is deep-rooted, long-lived (more than 100 years) and relatively combustible. Lentisk is unpalatable to most animals except goats and this may confer protection from grazing. Mature plants can withstand winter temperatures down to –9°C. Reported temperature range for growth is 12–40°C with optimum of 18–24°C. Suitable annual rainfall for growth is 200–2000 mm with optimum of 400–800 mm and soil pH range is 6.0–8.5. It protects soil from erosion and desertification risks.

3.2.3.5 *Ceratonia siliqua* L. -- An agrosilvopastoral leguminous tree (Louhaichi et al. 2020e)

*Ceratonia siliqua* L., commonly known as the carob tree or locust tree, is a long-lived evergreen legume tree native to the Mediterranean. It grows to 5–10 m in height in agricultural situations that feature crops, forestry and animal pasture (agrosilvopastoral systems) and has high ecological and socio-economic value. It is native to the Mediterranean region and tolerates drought well. It grows on a wide range of soils and has several traditional medicinal uses. It is a source of carob gumis a common food thickener and carob leaves and pods could be used to feed.

3.2.3.6 *Moringa oleifera* Lam. -- A multi-purpose legume tree well suited for agroforestry (Slim et al. 2021b)

*Moringa oleifera* belongs to the Moringaceae family. It is native to the northwest region of India, south of the Himalayan Mountain region. In recent centuries, this tree has spread along the tropical belt, from south India to southeast and west Asia, the Arabian Peninsula, sub-Saharan Africa and from Central America. Moringa oleifera can be used as alley cropping, animal forage, ornamental tree and in traditional medicine. Alley cropping with moringa is used to generate additional income, reduce soil erosion and, in the longer term, improve soil nutrient conditions.

The main important advantageous characteristic of moringa is its high productivity of fresh material (4-6 cuts /year = 50 to 80 t DM/ha). The chemical composition of moringa prove that leaves are good sources of nutrition for livestock (CP 20.20%). The nutritional characteristics of the moringa tree are excellent, so it can easily be used as a fresh forage material for cattle. Traditional (folk) medicine uses raw or crushed moringa seeds as a decoction for treating stomach pain, ulcers, poor vision, joint pain and for aiding digestion. The seed extract has been found to possess good antimicrobial activity against numerous
bacterial and fungal species. Moringa seeds are used as nature-based solutions for the problem of water purification.

3.2.3.7 *Prosopis cineraria* - A wonder tree for agroforestry in arid and semi-arid areas (Kumawat et al. 2014a)

*Prosopis cineraria*, known as *Khejri* in Rajasthan in northwest India, is one of the most drought-tolerant tree species and thrives in hot, arid regions with an annual rainfall of less than 500 mm. Native to areas such as the Arabian and Thar Deserts in western Asia and south Asia, it grows best with an average annual rainfall of 250–400 mm. Its roots can reach depths of 30 m accessing water that is unavailable to most other plants and animals. It is the state tree of Rajasthan and the national tree of the United Arab Emirates. Capable of withstanding a great variation in temperature, *Prosopis cineraria* easily copes with summer temperatures of up to 50°C and winter nights with temperatures around freezing.

It is drought-tolerant and is also resistant to heat and cold. It grows in a range of soils from sandy loam to clay loam and from flat plains to sand dunes. The forage is of high quality for ruminants and can be cut for feed once a year or every two years in drier areas. A medium-sized tree produces 45 kg of dry fodder at each lopping.

3.2.4 Other species

*Tirmania pinoyi* (Maire) Malenço - An edible fungal species and an important component of the mycological flora in arid and semi-arid rangelands (Louhaichi and Gamoun. 2021b)

‘Desert truffle’ refers to members of the genera Terfezia and Tirmania in the family Terfeziaceae, order Pezizales. Known as *terfes* or *kama*, they represent an important belowground component of arid and semi-arid rangelands. Desert truffle usually appears in the desert following the rainy season. Desert truffle has a high economic value and are the world’s most expensive mushrooms. Tunisian *terfes* are sold at a high price to the greatest chefs of the world because of their many virtues and special quality. Desert truffle has also constituted an important nutritious food and medicine since ancient times for the people of North Africa and southwest Asia. They are used as a meat substitute and consumed in large quantities due to their delicious taste and musky aroma. They have a unique nutritional profile of unsaturated fatty acids, vitamins, minerals and protein and have been used for eye treatment in folk medicine.
3.3 CONCLUSION, LESSONS LEARNT AND WAY FORWARD

**Rangeland management using sustainable grazing practices**

Maintaining rangeland plant diversity serves as an insurance policy for the survival of healthy rangelands, to provide a sustainable ecosystem of goods and services. The interactions of climate and increased grazing favour the establishment of unpalatable species, while reducing the distribution of preferred plant species. This pattern continues to provide one of the greatest challenges to the management of arid and semi-arid rangeland ecosystem structure.

The information generated using the ecologically based quantitative niche model that predicts current and future species distribution scenarios can be used by managers to determine the risk associated with change in current vegetation distribution of desired native plant species in the rangeland landscapes over time. However, to validate and further refine the model, further studies are needed that investigate the physiological thresholds, because of climate change scenarios as well as disturbance intensities for individual species of interest or value.

Soil scarification is recommended for bare and crusted soil. Depending on the geographic location, scarification should be implemented in advance of the early fall rainfall (usually one to two weeks before the first rain is expected). If the soil seed bank is depleted, scarification should be combined with direct seeding. Scarified areas should be protected to allow seeds to emerge and seedlings to establish. The established plants should be lightly grazed initially, with moderate grazing permitted thereafter. Combining soil scarification and reseeding a high nutritive forage species for example leguminous species in degraded silvopastoral areas in the semi-arid Mediterranean rangelands, would enhance the soil water
interaction and increase the water use efficiency resulting in a higher aboveground biomass. These outcomes need wider dissemination.

Planting shrubs is beneficial in reducing the effects of degradation such as soil erosion and in creating microhabitats for vertebrate and invertebrate fauna. Shrub biomass could also be used as livestock feed especially during dry periods. The establishment and management of shrubs requires that they receive a long enough period for them to recover lost biomass after a browsing and pruning event. Harvesting of water and its use when seedlings are being planted and established help to secure strong roots and soil contact. Species selection should be guided by rangeland development objectives, such as fodder production, wood production, dune fixation or erosion control. There is a need to strengthen the system that makes available suitable species of shrubs at the appropriate time for the target ecosystem.

During short-term rest from grazing (two years), vegetation cover, density, rangeland production and carrying capacity can be improved. During relatively rainy years, grazing for short periods (one year or less) is not harmful for rangeland vegetation in the dry areas. Adequate grazing can have a beneficial effect over the duration of the vegetative period of certain species and alternation of short periods of grazing with periods of vegetative rest is generally more favourable than strict or long-term protection. A maximum of two years of rest would be enough to sustainably manage the rangelands in southern Tunisia.

The vegetation response is impressive during rainy years. Such positive responses do not occur every year as the most common scenario under arid conditions is recurrent drought. Therefore, it would be a lost opportunity for pastoral communities if they are not allowed to use this abundant and rich biomass. From this perspective, development agencies have been keen to revise and update projects and programs for a more flexible approach linking administration with end-user needs based on scientific evidence. These findings have implications for the health of the arid rangelands of Tunisia and the livelihoods of pastoral communities. The revival of the traditional best practices under new arrangements adapted to current biophysical and socioeconomic conditions would be an excellent tool to mitigate the negative effects of frequent droughts, enhance livestock productivity and reduce the animal feed costs poor farmers are facing. These findings may contribute to strategies for addressing the extreme climatic variations that threaten rangeland and livestock sustainability. They also offer evidence for designing approaches that could be scaled out to other regions, such as the Middle East and North Africa.

Inappropriate grazing that causes decline in plant diversity alerts rangeland managers to consider suitable management changes. The decision on the duration, for which the rangelands are not be grazed, should not be decided upfront as it depends on the climatic and the site-specific conditions. Knowing that short grazing exclusion with adequate rainfall amount and distribution could be enough and offers a cost-effective technical option to ensure the sustainable restoration of arid rangeland. This flexible grazing management would also be more acceptable by the pastoral communities. Longer resting periods could have detrimental effects on arid rangeland vegetation, in addition to adding more pressure on the remaining rangeland areas open to grazing. These findings have vital management implications for development agencies and pastoral communities.
Under these conditions, it is important to consider a flexible approach to grazing management, depending on climate conditions and site specificity. The findings have contributed to the development of sustainable rangeland management strategies across the dry areas to strengthen the resilience of the pastoral communities. In terms of implementation, rangeland teams should visit the fields and assess biomass availability, to decide when to permit the controlled rapid grazing.

In Tunisia, the regional offices of OEP (the Livestock and Rangeland Authority) are responsible for deciding when controlled rapid grazing should be permitted, following field visits and measurements of biomass. Every office is expected to form a rangeland team composed of technical staff from OEP and staff from various relevant departments within Tunisia’s Ministry of Agriculture, Fisheries and Water Resources. The capacity development opportunities are provided to rangeland teams, equipping them with the knowledge and skills to conduct the required measurements, decide on the optimal carrying capacity and duration of grazing and disseminate appropriate information to inform planning. The strategy and process applied by the OEP could be an example for others to follow for sustainable management of rangelands.

*Rangelands through introduction of drought and salt-tolerant species*

ICARDA’s Rangeland Ecology and Management Unit aims to address the unsustainable use of resources induced by mismanagement, the adverse effects of climate change and an increasing demand for food and feed in the dry areas. ICARDA programs promote the enhanced quality and productivity of crop, forage and livestock, and the improved management of water resources through close cooperation with farmers and national researchers. Through ICARDA’s activities several shrubs, trees and grasses have been promoted with the aim to sustainably maintain rangelands, restore degraded rangelands and increase livestock productivity. A series of flyers/factsheets are designed to build awareness of sustainable rangeland management through best practices and well-adapted species among extension workers and those working in the agricultural research and policy sector.

Silvopasture offers multiple benefits for agro-pastoralists (Kumawat et al. 2014b). Traditionally, silvopasture – the integration of livestock and forage in an agro-forestry production system – has been common in most arid and semi-arid parts of India. This system, which involves planting trees or shrubs in rows with wide spacing, creates ‘alleyways’ where animals can graze on forage crops or native pasture. Silvopasture is ideal for arid and semi-arid environments: it can improve forage production in areas highly dependent on livestock production; is suited to drought-tolerant regions; and can be used to rehabilitate natural pastures – both in terms of productivity as well as species composition or biodiversity. In addition, combined with the diversification of forage crops in multi-crop systems, it can improve diet quality, extend the grazing system and improve the organic layer of soil by preventing soil erosion, contributing organic matter and improving water-holding capacity. This is achieved through increased water infiltration in the micro-catchments provided by shrubs and trees. Finally, the canopy of shrubs/trees provided by silvopasture creates micro-habitats and a refuge for native species and presents a way to sequester carbon and still allow for the grazing of livestock. As a result it is a system that addresses multiple problems while generating multiple benefits.
Appropriate management silvopasture requires relevant management skills to sustain the system. It constrains traditional mobility and requires protection and periodic maintenance for the system to be sustainable. In general, it takes two years to experience the benefits and there are substantial costs involved. Many site characteristics must be taken into consideration when establishing a silvopasture system, including slope, soil characteristics, climate conditions and appropriate plant species. While fodder shrubs or trees assist in reducing the feeding gap, they can only constitute up to one quarter to one third of the dry matter intake of small ruminants. As a result, grass must be provided or maintained between the rows. Species can vary by locality depending on site characteristics and local knowledge. Almost all shrub or tree species need to be transplanted - except for a few species that can be established through broadcasting or direct seeding. Planting before the rainy season has benefits that help establish roots. Selected grass species need to have the ability to adapt to low light, particularly when tree species are used, by moderating the efficiency of their photosynthetic apparatus. Selected plant species should be drought tolerant, moderate to highly palatable, and can withstand grazing. It is sometimes preferable to use multi-purpose trees that can also be used to grow fruits for human consumption. Rooting structure of both species needs to be considered so there is no competition between species. Plants that have allopathic effects on other plants should not be selected. Some silvopasture systems grow cash crops such as barely or wheat between the rows that are cut and carried, allowing animals to graze on the stubble and shrubs after harvest.

For the drylands of India, there are many well adapted planted shrubs/trees that can be considered when establishing a silvopasture system. Commonly planted trees that are used include *Ailanthus excelsa*, *Acacic nilotica*, *Prosopis cineraria*, *Ziziphus nummularia*, *Z. mauratiana*, *Tecomella undulata*, and *Dalbergia sissoo*, amongst others. The trees *Prosopis cineraria*, *Ziziphus nummularia*, and *Tecomella undulata* are commonly planted in arid zones with low rainfall, while *Dalbergia sissoo* is grown in the irrigated areas of arid regions. Fruit trees are also often cultivated such as *Cordia myxa*, *Ziziphus mauratiana*, *Phyllanthus emblica* and *Phoenix dactylifera*, but irrigation may be necessary depending on the species.

Dryland pastoral landscapes are characterized by unpredictable climate change and frequent ecological disasters such as drought and livestock diseases. The impacts of climate change will lead to more droughts that will affect millions of people in the world’s poorest regions. In addition, dryland inhabitants are increasingly affected by climate change as the resources to which they have access are marginal in nature. Arid and semi-arid regions are characterized by many conditions that limit establishment and growth of species. Given these scenarios, forage legumes have many advantages for use in improvement of rangelands and forage production. Salinity is one of major factors hampering many crops and forage systems. Legumes, which are known by their high nutritional values and good forage qualities, comprise glycophytes and several species adapted to extreme environments. Among these, the genus Lotus is widely distributed around the world and some species are limited in specific areas, such deserts, mountains and coasts. Possessing a range of adaptive attributes, makes the genus well suited for reclamation, renovation and restoration of marginal areas.
Shrub plantation also contributes to ecological sustainability of rangelands while aiming towards livelihood improvement. The degradation of rangelands is induced by overgrazing, over-gathering of firewood and conversion of the best rangelands into cropping land. Over-exploitation results in negative effects leading to soil erosion and the reduction of forage biomass for livestock. To alleviate the spread of rangeland degradation, planting shrubs provides a large amount of fodder for livestock, combats desertification and plays a key role in natural resource conservation. Based on the finding of ICARDA and its partners, shrub plantation has been promoted in semi-arid and arid areas (Louhaichi and Moyo, 2018). The integration of shrubs through alley cropping has the potential to improve both the sustainability and profitability of utilizing a piece of land, thus improving the livelihoods of smallholder farmers. The choice of species will depend on the annual rainfall amount, soil, topography, runoff, water harvesting potential of the site and the likelihood of environmental stresses such as drought, salinity and cold. Species selection is also guided by rangeland development objectives, such as fodder production, wood production, dune fixation or erosion control.

In arid and semi-arid areas, common fodder shrubs include *Atriplex halimus* (Mediterranean saltbush), *A. leucoclada* (Orache), *A. nummularia* (old man saltbush), *Bassia prostrata* (desert bush), *Salsola vermiculata* (Mediterranean saltwort) and *Haloxylon aphyllum* (saxaul). *Ceratonia siliqua* L. (carob tree), a long-living evergreen tree native to the Mediterranean, is commonly used to provide shade for livestock during hot summers. Certain shrubs/ trees contain anti-nutritional factors (secondary chemical compounds or toxins) which reduce the overall digestibility and palatability of their forage quality. Care must be taken to select highly adaptable species suited to the low rainfall and salt conditions of arid environments.

Reseeding is a practical and cost-effective technique that enhances ecological sustainability while strengthening system resilience. Combating land degradation in arid and semi-arid rangelands is essential to ensure the long-term productivity of these regions and the socio-cultural services these environments provide, such as grazing systems and the aesthetic and recreational values of the landscape.

The problem of rangeland degradation can be reversed through revegetation, for example through inclusion of various locally adapted native species in the reseeding. Reseeding involves sowing seeds directly into their final growing position and is applied on rangelands with an advanced degree of degradation, low plant density or poor productivity levels. Reseeding is beneficial as it reduces the high costs associated with raising seedlings from nurseries and transplanting them to fields. If properly implemented, this technique is particularly effective for rehabilitating steep slopes, or otherwise inaccessible areas. Reseeding reduces root deformities caused by seedlings outgrowing their containers or careless transplanting techniques. It can potentially yield high plant density at low costs and may also be an inexpensive means of providing wildlife habitats through a more diverse plant mixture which includes naturally regenerated plant species.

Establishing a seed collection from the local ecosystem is advisable to ensure availability when restoration begins and reseeding only those rangelands having sufficient potential to insure reasonable chances of
success. Reseeding will involve protecting the area from grazing. The effectiveness of reseeding is influenced by the quality and period of seed storage, which may increase dormancy and eventually lead to seed death. For many species, seeds should also be pre-treated before reseeding to break dormancy. When reseeding, hardpans and waterlogging are generally not suitable for plants. The common causes of reseeding failure are prolonged drought, heat injury and rodent depredation. With appropriate methods of soil preparation and careful choice of plant material, successful reseeding can however be made in low rainfall areas. For crusted soil, scarification is needed to allow seed and rain to enter soil (increased water infiltration), allowing emergence and subsequent establishment of the species. Seeds are sown when they have the best chances of germination, which is when moisture is plentiful. Using rangeland drill or hand broadcasting are the commonly used ways of reseeding. A mixture of species when reseeding is beneficial in maximizing land utilization and potentially yielding higher biomass yields within a piece of land, compared to monoculture planting.

Suitable species should be selected depending on management objectives and large numbers of highly viable seeds are required. A mixture of species and seed treatments are recommended to increase chance of establishment. This is because multiple species are far easier to handle as seeds than as seedlings. The choice of species for reseeding must focus on species which have early establishment vigour to ensure good root anchorage on the soil surface, weed competitiveness and drought tolerance.

Site characteristics for reseeding must be evaluated against the choice of species. For example: on shifting sand dunes seeding of Calligonum polygonoides gave a good germination of 85% and developed into beautiful stands of 60-90 cm in height. Leguminous shrub species which are drought and cold tolerant such as Hedysarum and Medicago species, are recommended for the reseeding technique, as these enrich the soil with nutrients. Grass species ideal for reseeding are Lolium perenne and Stipa lagascae.
REFERENCES


Alkhtib, A., Wamatu, J., Tolemariam, T. and Rischkowsky, B. 2019a. Genetic Variability in Food and Feed Traits of Early Maturing Desi Chickpea (Cicer arietinum) for Multi- Dimensional


Bedru et al. (2019). Assessment of small ruminant production system in Hadero Tunto Zuriya Woreda in Kembata Tembaro Zone of Southern Ethiopia and on farm evaluation of replacement value of cowpea (Vigna unguiculata) hay for concentrate mix on performance of sheep fed Napier grass (Pennisetum purpureum) as basal diet. MSc Thesis. Hawassa University, Ethiopia. https://hdl.handle.net/10568/106326


Gamoun, M. and Louhaichi, M. 2020a. Managing rangelands: promoting highly palatable species resistant to harsh desert climatic conditions; Gymnocarpos decander Forssk. a highly
palatable species facilitating the establishment of annuals vegetation under arid climate. Lebanon: International Centre for Agricultural Research in the Dry Areas (ICARDA).
https://hdl.handle.net/20.500.11766/11828

Gamoun, M. and Louhaichi, M. 2020b. Managing rangelands: promoting highly palatable species with good nutritive value; Plantago albicans L. a perennial herbaceous species that is highly palatable and widely distributed across the Mediterranean region. Lebanon: International Centre for Agricultural Research in the Dry Areas (ICARDA).
https://hdl.handle.net/20.500.11766/11829

https://hdl.handle.net/20.500.11766/12435

https://hdl.handle.net/20.500.11766/12436

Gamoun, M. and Louhaichi, M. 2021c. Managing agrosilvopastoral systems: controlling invasive perennial species; Peganum harmala L. noxious invasive species, toxic to livestock but medicinally important
https://hdl.handle.net/20.500.11766/12437

https://hdl.handle.net/20.500.11766/10394

https://hdl.handle.net/20.500.11766/12434

https://doi.org/10.1016/j.eja.2019.02.012

https://hdl.handle.net/20.500.11766/10395


Parameters as Affected by Planting Time and Agronomic Management in a Semi-Arid Region of India. *Agronomy* 11(8): 1647. [https://doi.org/10.3390/agronomy11081647](https://doi.org/10.3390/agronomy11081647)


Beirut, Lebanon: International Centre for Agricultural Research in the Dry Areas (ICARDA). https://hdl.handle.net/20.500.11766/8494


Louhaichi, M. and Hassan, S. 2018. Screening for cold tolerant cactus species (Opuntia ficus indica) under West Asia conditions. https://hdl.handle.net/20.500.11766/8278


Louhaichi, M., Moyo, H. and Hassan, S. 2021e. Managing agrosilvopastoral systems: promoting forage legumes species; Astragalus cicer L. excellent perennial forage legume resistant to grazing https://hdl.handle.net/20.500.11766/12439

Louhaichi, M., Slim, S. and Rhomdhane, O. 2021f. Managing agrosilvopastoral systems: promoting native forage legume species; Hedysarum carnosum Desf. an important halophytic pastoral legume that tolerates stressful conditions in arid and semi-arid rangelands. https://hdl.handle.net/20.500.11766/12441


Louhaichi, M., Gamoun, M., Hassan, S. and Slim, S. 2021i. Managing agrosilvopastoral systems: promoting shrub legume species; Medicago arborea L. is an important perennial woody leguminous shrub with great forage and nitrogen-fixing potential https://hdl.handle.net/20.500.11766/12442


Mengesha, M., Bezabih, M., Mekonnen, K., Adie, A., Duncan, A.J., Thorne, P. and Tolera, A. 2017. Tagasaste (*Chamaecytisus palmensis*) leaf supplementation to enhance nutrient intake and


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