Impact of agroforestry on land productivity and production systems resilience in drylands of Morocco

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Summary - The arid climatic context of Morocco and the widespread degradation of natural resources constitute the origin of the decline in agricultural production. The challenges generated by this situation encourage the development of innovative and sustainable technologies to maintain and secure this production. These technologies must be part not only of adaptation and mitigation of climate variations, but also of meeting needs (food, income, well-being), while conserving natural resources. In this context, agroforestry is an agricultural practice to be recommended as it can respond to many current challenges (biodiversity, diversified production, carbon storage). This work aims to characterize the performance of the agroforestry system in the arid climate of western Morocco. To do this, three year comparisons between yields of plant and organic and mineral composition of the soil were made. For each crop, agroforestry systems (AFS) were compared to monoculture systems (MS). The introduction of shrubs and trees into agricultural plots has made it possible to improve the production and quality of fallow land as well as fodder and cereal crops. Indeed, unlike the floristic diversity of the fallow which was not much affected by the presence of trees and shrubs, the density and phytomass of herbaceous plants and intercrops were improved. And it is the group of argan and carob trees which showed the most convincing results. This is due to the creation of optimal conditions for the growth of plant species, especially in terms of soil porosity for argan tree and nitrogen fixation for carob tree and alfalfa shrub. In fact, the use of shrubs in cereal fields, showed very significant differences in density, so the densities of barley (Hordeum vulgare) in January (375 plants/m²) and March (351 plants/m²) in AFS were superior to those of MS (350 plants/m² in January and 308 plants/m² in March). Similarly, biomass and dry matter of faba bean (Vicia faba) associated to argan trees (Argania spinosa) and carob trees (Ceratonia siliqua), and of barley (Hordeum vulgare) associated to Atriplex numularia, were more important in AFS than in MS, despite limiting climatic conditions and possible competition between trees and crops. In addition, the crops in AFS contain more nitrogen and Total Nitrogenous Matter (TNM) in the plant material than MS. On average, the faba bean contains 7.5% of N grown alone, although associated to carob trees it contains 14.1% and 13.1% with argan trees. Therefore, the plant matter has a better forage quality in AFS. We also found that for the organic matter and total nitrogen in the soil, the difference is significant between the two systems and the soil is richer in organic matter (OM) and total nitrogen in AFS than in MS. In fact, the soil in barley crop for AFS contains 4.77% of OM and 3.82% for MS, as well as the faba bean-carob trees association plot (where the carob trees are more than 10 years old) contains 5.86% of OM vs 2.31% in MS. Thus, the intercropping plant in AFS contains more TNM and better nutritional quality and the soil is richer in OM and total Nitrogen. Agroforestry systems are, therefore, more productive, and efficient and would constitute a solution for sustainable agricultural production in drylands of Morocco.

Keywords: *Agroforestry, drylands, rainfed crops, fodder, fallow, soil*

Impact de l'agroforesterie sur la productivité des terres et la résilience des systèmes de production dans les zones arides du Maroc

Résumé - Le contexte climatique aride du Maroc et la dégradation généralisée des ressources naturelles constituent l'origine du déclin de la production agricole. Les défis générés par cette situation encouragent le développement de technologies innovantes et durables pour maintenir et sécuriser

cette production. Ces technologies doivent contribuer non seulement à l’adaptation et à l’atténuation des variations climatiques, mais aussi à répondre aux besoins (alimentation, revenus, bien-être), tout en préservant les ressources naturelles. Dans ce contexte, l’agroforesterie est une pratique agricole à recommander car elle peut répondre à de nombreux enjeux actuels (biodiversité, production diversifiée, stockage de carbone). Ce travail vise à caractériser les performances du système agroforestier dans le climat aride de l’ouest du Maroc. Pour ce faire, des comparaisons sur cinq ans entre les rendements des plantes et la composition organique et minérale du sol ont été réalisées. Pour chaque culture, les systèmes agroforestiers (SAF) ont été comparés aux systèmes de monoculture (SM). L’introduction d’arbustes et d’arbres dans les parcelles agricoles a permis d’améliorer la production et la qualité des jachères et des cultures fourragères et céréalières. En effet, contrairement à la diversité floristique des jachères qui était peu affectée par la présence d'arbres et d'arbustes, la densité et la phytomasse des plantes herbacées et des cultures intercalaires ont été améliorées. Et c'est le groupe d'arganiers et de caroubiers qui a montré les résultats les plus probants. Cela est dû à la création de conditions optimales pour la croissance des espèces végétales, notamment en termes de porosité des sols pour l’arganier et de fixation de l’azote pour le caroubier et l’arbuste de luzerne. En effet, l'utilisation d'arbustes dans les champs de céréales a montré des différences de densité très significatives, ainsi les densités de l'orge (*Hordeum vulgare*) en janvier (375 plants/m²) et mars (351 plants/m²) dans SAF étaient supérieures à celles de MS (350 plants/m² en janvier et 308 plants/m² en mars). De même, la biomasse et la matière sèche de l'orge (*Hordeum vulgare*) associées à *Atriplex nummularia*, étaient plus importantes en SAF qu'en MS, malgré des conditions climatiques limitantes et une éventuelle compétition entre arbres et cultures. De plus, la matière végétale présente une meilleure qualité fourragère en SAF. Nous avons également constaté que pour la matière organique et l'azote total du sol, la différence est significative entre les deux systèmes et le sol est plus riche en MO et en azote total en SAF qu'en MS. En fait, le sol de la culture d’orge pour SAF contient 4,77 % de MO contre 3,82 % pour MS.
Ainsi, la plante intercalaire en SAF contient plus de MAT et une meilleure qualité nutritionnelle et le sol est plus riche en MO et en Azote total. Les systèmes agroforestiers sont donc plus productifs et efficaces et constitueraient une solution pour une production agricole durable dans les zones arides du Maroc.

Mots clés : *Agroforesterie, zones arides, cultures pluviales, fourrage, jachère, sol*

تأثير الزراعة الحراجية على إنتاجية الأراضي والموارد الطبيعية في الأراضي الجافة بالمغرب

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ملخص-يشكل المناخ الجاف في المغرب والتدهور الواسع النطاق للموارد الطبيعية سبب انخفاض الإنتاج الزراعي. تدفع التحديات الناتجة عن هذا الوضع على تطوير تقنيات مبتكرة ومستدامة للحفاظ على هذا الإنتاج وتأمينه. ويجب أن تساهم هذه التكنولوجيات ليس فقط في التكيف مع التغيرات المناخية والتخفيف من آثارها، بل وأيضاً في تلبية الاحتياجات (الغذاء، والدخل، والرفاهية)، مع الحفاظ على الموارد الطبيعية. وفي هذا السياق، تعتبر الحراجة الزراعية ممارسة زراعية يوصى بها لأنها يمكن أن تستجيب للعديد من التحديات الحالية (التنوع البيولوجي، الإنتاج المتنوع، تخزين الكربون). يهدف هذا العمل إلى توصيف أداء نظام الزراعة الحراجية في المناخ الجاف لغرب المغرب. وللقيام بذلك، تم إجراء مقارنات على مدار خمس سنوات بين إنتاجية النباتات والتركيبة العضوية والمعدنية للتربة. بالنسبة لكل محصول، تمت مقارنة أنظمة الحراجة الزراعية (AFS) بأنظمة الزراعة الأحادية(SM) وقد أتاح إدخال الشجيرات والأشجار إلى الأراضي الزراعية تحسين إنتاج ونوعية الأراضي البور ومحاصيل الأعلاف والحبوب. في الواقع، على عكس التنوع النباتي الذي لم يتأثر كثيرًا بوجود الأشجار والشجيرات، تم تحسين الكثافة والكتلة النباتية للنباتات العشبية والمحاصيل البينية. وقد أظهرت مجموعة أشجار الأرغان والخروب نتائج مقنعة. ويرجع ذلك إلى تهيئة الظروف المثلى لنمو الأنواع النباتية. أظهر استخدام الشجيرات في حقول الحبوب اختلافات كبيرة جدًا في الكثافة، مثلا كثافات الشعير (*Hordeum vulgare*) في يناير (375 نباتًا/م2) ومارس (351 نباتًا/م2) في SAF كانت أعلى من تلك الخاصة SM. (350 نبات/م2 في يناير و 308 نبات/م2 في مارس). وبالمثل، كانت الكتلة الحيوية والمادة الجافة للشعير المرتبطة بـ *Atriplex nummularia* أكبر في SAFمنها في SM، على الرغم من الظروف المناخية المحدودة والمنافسة المحتملة بين الأشجار والمحاصيل. بالإضافة إلى ذلك، تتمتع المواد النباتية بجودة علفية أفضل في SAF .لقد وجدنا أيضًا أنه بالنسبة للمادة العضوية وإجمالي نيتروجين التربة، يكون الفرق كبيرًا بين النظامين وأن التربة أكثر ثراءً في OM والنيتروجين الكلي في SAF مقارنة بـ SM ، بحيث تحتوي تربة محصول الشعير في SAF على 4.77 OM %مقارنة بـ 3.82% في .MS وبالتالي، تحتوي الزراعة البينية SAF على المزيد من MAT وجودة غذائية أفضل والتربة أكثر ثراءً في OM والنيتروجين الكلي. وبالتالي فإن أنظمة الزراعة الحراجية أكثر إنتاجية وكفاءة وتشكل حلاً للإنتاج الزراعي المستدام في المناطق القاحلة في المغرب.

الكلمات المفتاحية: *الحراجة الزراعية، الأراضي الجافة، المحاصيل البعلية، الأعلاف، الأراضي الراقدة، التربة*

Introduction

Morocco is a developing country experiencing demographic, social and political transitions. The challenges he faces are considerable. Agriculture, being the leading wealth-creating sector and the largest employer in the country (Lahlimi, 2017), occupies a vital place economically, socially, and environmentally. Climate change, and its consequences on water resources and soil degradation, strongly influence Moroccan agriculture. Thus, in terms of total Useful Agricultural Area (UAA), we see that agriculture in Morocco is dominated by areas with limited potential, in fact, the semi-arid alone occupies 44% of the UAA, or 3.839 million ha (Harbouz et al., 2019). Production systems are complex and rely on the integration of crops and livestock and the gap between potential and the yields obtained by farmers is still significant (Srairi, 2011).

This situation calls into question the conventional practices of Moroccan agriculture in arid and semi-arid zones and their potential to meet production needs in the face of serious economic and climatic challenges. Hence, there is a need to adopt new approaches to this sector development for adaptation to droughts and the restoration of natural resources (soils and vegetation).

Agroforestry is a method of using agricultural land combining trees and crops and/or livestock in order to obtain products or services useful to humans. It is a practice that has become essential in sustainable land use worldwide (Guitton et al., 2009). It is from this perspective that we are witnessing in Morocco an evolution of agroforestry and silvopastoral areas outside of wooded areas. In particular, olive plantations have evolved rapidly within the framework of the Green Morocco Plan (PMV) to approach one million hectares, approximately 75% of which are associated with annual crops.

In Morocco, agroforestry, at all times, was particularly widespread in mountain areas and oases, where farmers seek to maximize the profitability of their often-cramped agricultural land (Daoui, 2012). But although agroforestry is traditionally practiced in Morocco, little scientific research has addressed the subject (Daoui, 2012). This constitutes an obstacle to its evolution and expansion.

In these ecosystems, the functions of trees depend on their number, structure, density, and canopy distribution (Bora et al., 2021). Studying these parameters can provide insight into the logic by which tree species exploit resources in their canopy habitats and how this impacts the herbaceous layer. The ultimate objective of this research is to determine the effect of the introduction of the tree on the productivity of cultivated land and the protection of natural resources (water, soil and biodiversity).

Research context

With the exception of the northwestern region of Morocco which is relatively well watered and enjoys a temperate climate, the rest of the regions are semi-arid to arid, with increasing aridity towards low latitudes (the south of the country). The climate of arid and semi-arid regions is continental, with low annual precipitation which varies from one year to another, concentrated mainly in the November-February period, and allowing a restricted growth period (4 to 5 month). In addition to this low rainfall, temperatures are relatively high in spring and very high in summer, which can exceed 40°C and lead to rapid loss of soil moisture through transpiration by plants and direct evaporation. Due to climate change, we expect more reduction in rainfall and more heat during the 21st century (Mrabet et al., 2012).

The soils of these regions are generally shallow and poor in organic matter, two characteristics which do not allow the storage of water in the soil. They support a weak and precarious vegetation cover, further accentuating the phenomenon of desertification. Because of this low rainfall, high evapotranspiration and low soil moisture retention, aridity manifests itself, with even more intensity as soil and water resources continue to degrade.

At the same time, the arid and semi-arid regions of Morocco are home to a significant portion of the population and agricultural activity based essentially on the integration of livestock breeding and often continuous cereal crops. Wheat and barley are commonly grown. The pressure of livestock farming on rangelands and cultivated soils leaves no chance for the soil to reconstitute its organic matter. Especially since the minimum input mode which is the common practice of cereal growing in these regions does not make it possible to restore the exported mineral elements of the soil and restore its chemical fertility. In this situation of degradation of natural resources and the strong pressure of livestock on the meager vegetation in loss of productivity, on the one hand, and the low contribution of crops in feeding livestock within the farm, on the other hand, the sustainability of such a system is at risk.

The combination of trees and crops has considerable advantages, particularly in the area of soil protection and improving their productivity. Likewise, agroforestry is seen as promising for mitigating climate change, while improving agricultural productivity and food security. Agroforestry also provides ecosystem services such as preserving and improving biodiversity, efficient use of resources and soil health. In addition, trees also have the capacity to reduce groundwater pollution by limiting the leaching of nitrates to the deeper layers of the soil, which is rather positive for drinking water catchment areas which will logically be less polluted. Certain tree species have particular properties allowing them to fix nitrogen. They thus make it possible to enrich deficient soil with nitrogen and consequently the cultivation of plants that need it, which would reduce the use of chemical inputs. But, firstly, the decomposition of dead leaves and roots of trees creates humus, an organic matter rich in biological activity, significantly improving soil fertility. Trees also play a role in limiting the effects of global warming: they absorb CO_2 and store carbon. Thus, what is true when it comes to combating deforestation in the world's primary forests is true in the same way at the scale of the agricultural plot. It is also this contribution of trees that must be highlighted. Finally, trees end up producing fodder, fruits, firewood, lumber, etc., which contributes to the diversification of agricultural production.

There are different agroforestry systems depending on the associated crops. And it is the combination of different uses of the same soil that will generate interesting interactions in terms of optimizing resources, increasing biodiversity and improving the environmental conditions of crops, particularly through the creation of a microclimate. In agroforestry, the complementarity of crops is always sought because it allows natural resources to be optimized. This is the case of the layering of crops which allows tall trees to take full advantage of the sun's rays and low crops around them to protect themselves from the heat and wind, and root systems to exploit different horizons of the soil.

The work presented in this chapter includes a synthesis of the studies carried out in the experimental station of the CRRA (Regional Center for Agronomic Research) of INRA in Settat over the last five years. It consists of comparing the productivity of crops grown in a monoculture system (MS) and an agroforestry system (AFS) and the quality of the soil. The objective is to determine the effect of agroforestry on agricultural land productivity and soil in arid and semi-arid regions of Morocco.

The work consists of studying different vegetation and soil parameters over several years. Three different plantations based on argan, carob and *Medicago arborea* are compared to a plot without trees. For each plot, samples are taken in three locations between the tree rows; below the canopy representing maximum tree influence (shade + roots), between the tree and the middle of the aisle with intermediate tree influence (less shade and roots) and in the middle of the aisle marking minimal influence of trees (little shade, few roots). For the plot without trees, the samples are taken at random. Samples are taken at the end of each month (December, January, February, March and April) to estimate diversity (species and number of plants per species), density and fresh weight for intercropping vegetation as well as organic matter levels (OM), carbon (C) and nitrogen (N) in the soil.

Moroccan agroforestry systems

In Morocco, agroforestry is practiced in different climatic conditions but remains dominant in mountain areas and in oases where farmers seek to maximize the profitability of their agricultural land. Agroforestry systems have been based on olive trees and annual crops for several centuries. Diagnostic studies carried out in Morocco revealed that around 75% of olive plantations are associated with annual crops, such as cereals and food legumes (Daoui, 2012).

In arid and semi-arid areas, Atriplex was associated with the alley cropping system with barley, oats or alfalfa, it played an important role as a windbreak, for protection of the soil and the creation of a favorable microclimate, allowing other forage species to increase their productivity (Chriyaa and El Mzouri, 2004). The solution that has given the best results in rainfed arid zones, so far, is the association of dominant cereal crops, such as barley, with fodder shrubs. The latter, thanks to their great capacity to resist drought, to the action of improving the soil exerted by the contribution of organic matter and to the capacity of the roots to sink into the soil, have beneficial effects on the environment and ecosystem productivity. The forage shrubs which have given the best results are those of the Atriplex genus, in particular *Atriplex halimus* and *Atriplex nummularia* (Arif et al., 1994).

Numerous studies have highlighted the fact that by combining the cultivation of barley with fodder shrubs belonging to the Atriplex genus, the production of the cereal increases (Chriyaa and El Mzouri, 2004); in addition, livestock can graze on barley stubble and Atriplex shrubs in summer and autumn. From a nutritional point of view, research has demonstrated that integrating livestock feed with forage shrubs and prickly pear cacti provides excellent results (Chriyaa, 2007). Indeed, Atriplex has a high level of nitrogen and provides low energy intake, while Opuntia is particularly rich in energy and water. Additionally, Atriplex makes an excellent straw supplement and Opuntia increases its intake (Chriyaa, 2006); both species represent a good source of protein and can replace soya in animal feed, helping to reduce livestock costs (Nefzaoui and Ben Salem, 2002). The combination of these two fodder resources makes it possible to satisfy the food needs of livestock, reduce pressure on pasture lands and prevent degradation and desertification.

Agroforestry in Moroccan arid and semi-arid zones

In Moroccan arid and semi-arid zones, water constitutes the major factor limiting agricultural production. Water availability is determined by low and unpredictable rainfall, generally shallow, degraded soils with insufficient storage capacity, and high temperatures at the end, middle and/or beginning of the crop cycle. This results in a limited and highly variable production potential.

The economic pressure on the land has resulted in increasing recourse to the continuous cultivation of cereals. Exploitation of marginal lands and overgrazing of rangelands have become common practices. This resulted in mining of the environment materialized by a reduction in productivity and a degradation of natural resources (soil, vegetation, and water), leading to a worrying weakening of the environment which the production techniques currently practiced only aggravate.

To adapt to these changes in a sustainable way or even to mitigate them, it is therefore necessary to make these agroecosystems more resilient in the face of lack of water and variability in rainfall. Agroforestry proves to be a suitable alternative which can bring several benefits compared to conventional agriculture, whether for natural vegetation, notably fallows, or intercropping.

Agroforestry and fallow

The fallow technique is a very old practice in the arid Moroccan regions. It is experiencing a reduction following increased pressure on agricultural land. The main role of fallowing is the provision of free fodder units throughout crop cycles to meet livestock needs. According to El Koudrim (2021), the share of fallow at the zone level hardly exceeds 13 to 20%. And paradoxically, this share is even lower (less than 4%) in areas known for their sheep and goat breeders. However, in increasingly recurrent dry years, this share increases considerably to exceed 50% of the surface area. Indeed, when the year promises to be difficult (dry), the farmer refrains from cultivating his land and instead leaves it fallow for grazing.

The introduction of trees creates interactions with natural vegetation and can influence plant biodiversity and primary fallow productivity. These interactions can be positive (synergistic) or negative (antagonistic). Therefore, the productivity of this agroforestry system is ultimately the net result of positive and negative interactions, above and below ground, between trees and natural species.

At Chaouia, the natural fallow vegetation is steppe in nature with a mixture of annual and perennial species on generally shallow to skeletal soils. The floristic inventory provides information on a great plant diversity with the presence of several interesting species for improving the quantitative and qualitative productivity of pasture land.

The natural vegetation of the fallow is made up of several families with a dominance of Asteraceae and Poaceae. These families therefore constitute the herbaceous layer of the cultivation land in these areas. In second place comes the Fabaceae family with the presence of fodder legumes of nutritional interest such as Vicias and Astragales (Figure 1).
Concerning the biological type, we note a predominance of Hemicryptophyte and therophyte species (Figure 2). The latter, also called annuals, are present during a limited period of the year, which implies limited fodder availability. They are

herbaceous and their vegetative bud is exposed to herbivory. They also have shallow roots and cannot maintain the soil, which is thus exposed to water and wind erosion.

There are a large number of hemicryptophytic (perennial) species and they, on the other hand, have more developed root systems compared to annuals, but can compete with trees especially underground during the first years of planting.

Generally, canopies amplify the diversity of understory vegetation differently depending on the tree species. In our case, as the plantations are still young, the floristic diversity of tree alfalfa and argan is similar to the system outside the forest and it is lower for carob (Figure 3).

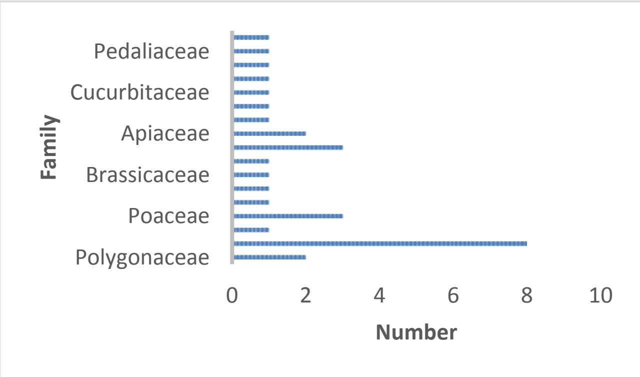

Figure 1. Distribution of species by family

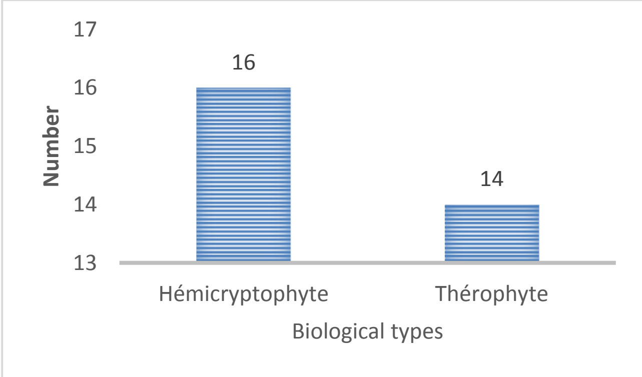

Figure 2. Distribution of species according to biological type

On the other hand, it should be noted that the influence of woody plants on the cover of the herbaceous understory can be positive or negative depending on the sampling location, the species present and the climate. Indeed, woody species can alter the density and vigor of understory plants, which can generate different herbaceous species composition patterns beneath the tree canopy and beyond. Several studies concluded that herbaceous composition and distribution patterns under the canopy changed as trees increased in size (McPherson et al. 1991).

Generally, trees enhance the density of understory vegetation compared to surrounding open areas. Thus, the density is higher between the center of the alley and the trees because the species benefit from the good porosity created by the roots of the trees and also by the light and they are less affected by competition. This is true for tree alfalfa and argan. Likewise, when approaching these two types of trees, the density of the perennial herbaceous layer decreases and that of the annuals increases because the latter are less demanding in pedoclimatic conditions. This density, on the other hand, is less important for the carob tree, although it is a nitrogen-fixing legume species (Figure 4).

Likewise, below the trees, sciaphilous species are more abundant compared to heliophilous species. And it is *Sinapis arvensis* L. which is the most abundant and which gives higher performances under shady conditions, especially with the carob tree. So it would be an interesting species to maintain with denser trees, especially since it is palatable to animals and has acceptable nutritional value. For other species, it was difficult to distinguish whether a species is sciaphilic or heliophilic since there were very high fluctuations between different locations relative to the tree. But we can say that *Calendula officinalis* L. as well as *Urtica urens* L. remain the most abundant species in sunny and shaded conditions for all plantations.

Also, the phytomass is affected by the presence of trees. It is higher, especially, between the center of the path and the trees because the species benefit from the good porosity created by the tree roots and by the light and there is less competition. This is true for tree alfalfa and the carob tree. But approaching the trees, the biomass of the herbaceous layer tends to decrease for the three types of plantations (Figure 5).

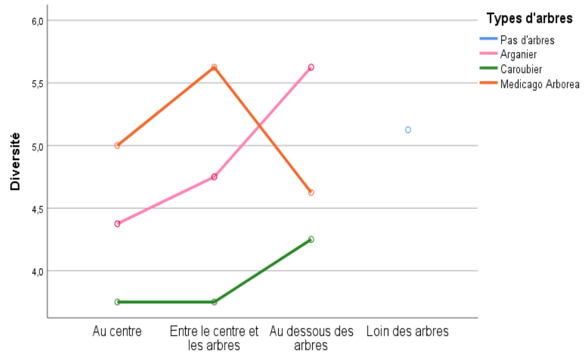

Figure 3. Floristic diversity depending on the distance from the tree

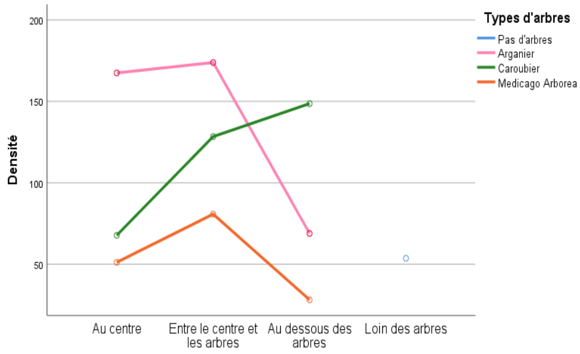

Figure 4. Vegetation density versus distance from tree

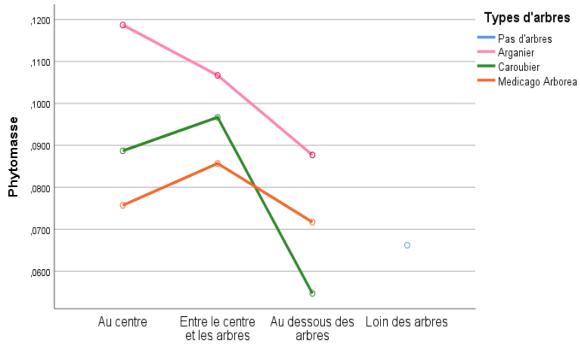

Figure 5. Phytomass compared to distance from the tree

As a corollary, the spatial configuration and abundance of plant species in arid zones are dictated by complex and dynamic interactions between trees and plant species (Scholes and Archer, 1997). Ludwig et al., 2001 showed that grass composition is higher under trees than in open areas in arid and semi-arid areas, due to availability of nutrients in the soil and shade created by tree canopies. Increased soil moisture availability due to hydraulic uplift (Ludwig et al., 2001) could also increase the composition and productivity of grass under tree crowns. Thus, in semi-arid African savannahs, where there is extreme variation in water and nutrients, large trees typically modify the microclimate and soil properties, leading to complex local interactions between vegetation beneath their canopies (Mitchell et al., 2012). These results were verified in our case for tree alfalfa with regard to diversity and for carob and argan for density and phytomass. In fact, the influence of trees on the plant communities below would be site and plant species specific (Kahi et al., 2009; Mitchell et al., 2012).

Ludwig et al. (2004) showed that competition for soil moisture and nutrients between trees and herbaceous species in semi-arid African savannahs, can lead to lower herbaceous swards under tree canopies as opposed to canopies exterior. Our study showed that the competitive effects of trees on the composition of understory vegetation outweighed the facilitative effects of trees and herbaceous species with respect to diversity for carob and density and phytomass for tree alfalfa. There is also an inhibitory effect exerted by the carob tree on the germination of adjacent plant species which could induce low diversity.

Generally speaking, trees improve the conditions for growth and development of their immediate habitat in arid and semi-arid environments. Thus by reducing air temperature, solar radiation and wind speed, trees reduce the ETP in the shaded area. According to Le Houerou & Popov (1981), the reduction in the maximum daily temperature of 2.5°C would correspond to a reduction in the ETP of approximately 147 mm/year at ground level. Thus, the screening function of woody vegetation reduces the ETP at the level of the herbaceous cover.

Furthermore, and contrary to what we can claim, our study shows that the productivity of herbaceous vegetation is lower under leguminous tree species compared to non-leguminous tree species. Indeed, the argan tree had a higher phytomass and density compared to the carob tree and *Medicago arborea.* Hartwig (1998) found that the contribution of leguminous trees to understory herbaceous vegetation could be affected compared to non-leguminous trees in arid areas. Indeed, legume trees may not fix nitrogen efficiently during dry seasons under conditions of high temperature, low phosphorus availability and high grazing intensity (Treydte et al., 2007). However, in general, legumes improve soil nitrogen levels and facilitate plant growth compared to non-nitrogen-fixing trees (Barbier et al., 2008). In fact, atmospheric nitrogen fixation by legumes improves soil nutrient levels which would lead to the presence of greater species diversity and higher growth of herbaceous vegetation.

Typically, recording the effects of tree cover on understory herbaceous plant communities is quite difficult due to the diversity of plant and tree species (Hulme et al., 2013; Stricker et al., 2015). The productivity of herbaceous vegetation, whether in the undercanopy habitat or adjacent intercanopy habitat of tree species, is influenced by tree type (Menezes et al., 2002) and l associated environment (Burrows, 1993). Mathakuta et al. (2019) assert that medium-adapted woody plants have a strong ability to penetrate harder soils with their taproots with a lower rate of nutrient and water absorption. According to Linstadter et al. (2016), the canopy of native trees can, therefore, moderate the heat of the sun, stabilize soil temperature and minimize evaporation to increase soil moisture content in its immediate environment. And as humidity is one of the main limiting factors for the growth of herbaceous plant species in arid and semi-arid areas, the effects of native tree canopy can help reduce solar radiation, stabilize temperature soil and evapotranspiration to increase soil moisture content. Similarly, the structure and density of tree canopies have a strong influence on leaf temperature, photosynthetic processes, water conductance and gas exchange characteristics which, in turn, affect herbaceous vegetation in understory habitats (Smith and Hughes, 2009).
However, woody plants not adapted to a given environment have a weak root structure to penetrate harder soils. As a result, the shorter lifespan of roots can create a situation where they can compete with herbaceous vegetation for nutrients and water. Competition for soil moisture between the roots of herbaceous species and non-native trees can result in reduced biomass of perennial herbaceous plants in canopy habitat compared to adjacent inter-canopy habitat. On the other hand, the structure of the SAF vegetation could contribute to the conservation and recovery of soils intended for production by an increase in the diversity of edaphic fauna which plays a primordial role in the degradation of organic matter. and its transformation into mineral matter absorbable by trees and plants (Smith and Hughes, 2009). Lassau and Hochuli (2004) indicated that floristic diversity contributes to the maintenance and conservation of faunal diversity, thereby helping to maintain ecological balance in ecosystems.

Agroforestry and rainfed crops

Fodder production in agroforestry

In the arid and semi-arid zones of Morocco, livestock systems have undergone profound changes. Previously, they were characterized by mobility, the use of natural resources, the abundance of forage available on rangelands and the importance of livestock breeding activity. Today, these systems seem to have a tendency towards sedentarization, appropriation of rangelands and individual exploitation (El Koudrim et al., 2003). This situation results, on an ecological level, by massive clearing and cultivation of the best pastoral sites (El Koudrim et al. 2014), and on a socio-economic level, by a diversification of livestock production and by weak integration between agriculture and livestock breeding, at a complete disadvantage for the latter (Boulanouar and Matthess-Guerrero, 1997, Tarhzouti et al., 2006, El Koudrim, 2021).

However, the livestock production subsystem is an essential component of the farm production system in drylands, and several constraints hinder the development of the sector. Indeed, the weakness and irregularity of the rainfall leading to a fluctuation in the food availability of the livestock resulting in the high cost of livestock feed and the low productivity of the animals, the low area reserved for fodder crops, a diet based mainly on cereal crop residues and continuously degrading rangelands, the low nutritional quality of food resources and the fairly advanced degradation of natural resources (Magnan et al. 2012, El Koudrim et al. 2021). Thus, filling the fodder deficit depends largely on the diversification of food resources and the availability of species with better tolerance to water stress. The rational exploitation of these areas must be focused on restoring a plant cover capable of producing even during critical seasons of drought. Agroforestry offers this possibility and allows permanent cover and continuous production, particularly of quality fodder. This is particularly the case for the use of fodder trees and shrubs.

Alley cropping is an alternative for feeding livestock in arid areas. It has been tried in several arid regions of Morocco (Figure 6). In this agroforestry system, forage shrubs (*Atriplex nummularea*) are planted in rows with annual crops in the aisles. Rows of shrubs have many advantages: soil conservation, production of livestock feed, shelter effect limiting evapotranspiration and windbreak. This system is particularly beneficial during periods of drought. The association of *Atriplex nummularia* and cereals or fodder shows obvious results in Moroccan arid zones, whatever the climatic year.

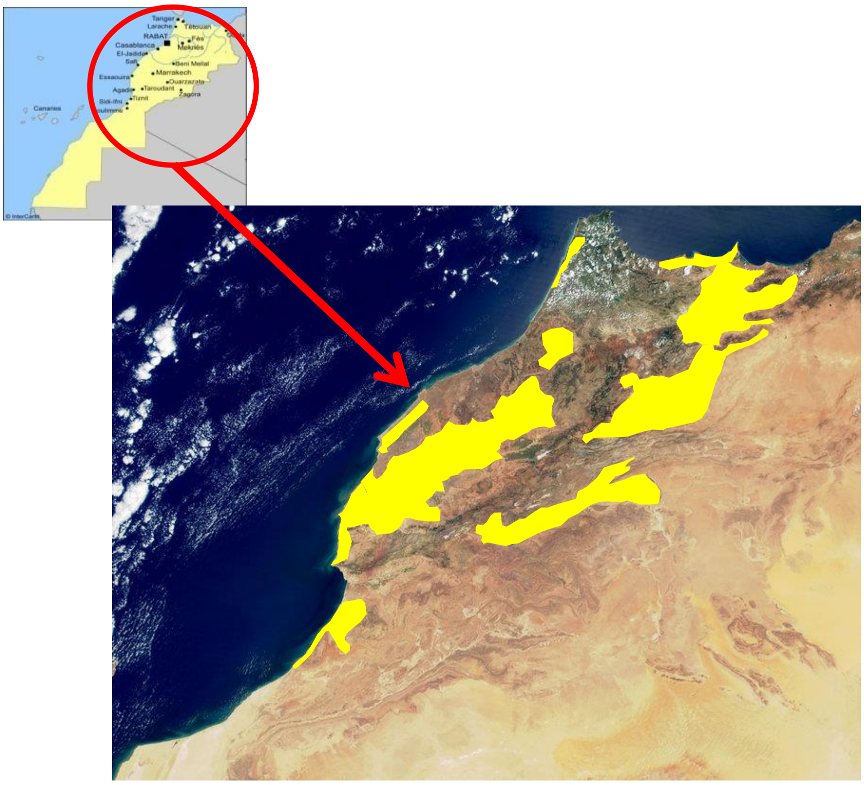

Figure 6. Recommended areas for atriplex alley cropping (Chriyaa et El Mzouri, 2004)

In Oued Zeem, for example, the presence of Atriplex allowed a 25% increase in the yield of forage crops, in normal and dry years, which corresponds to a land equivalent ratio (LER) of 25% and 33% more for the alley-cropping plot, respectively for a dry year and a normal year (Table 1). In addition, Atriplex leaves are appreciated by livestock and their yield varies from 0.3 to 1.2 t/ha (Boulal, 2001).

Table 1. Importance of forage production in alley cropping

	Without shrubs FM Kg/ha	**With shrubs FM Kg/ha**	**Production gain (%)**	**Gain in ha equivalent**
2014-2015 (340mm)	6024	8000	25	0.33
2015-2016 (210mm)	3500	4375	25	0.25

However, high shrub density can influence the productivity of intercrops. This effect is more often linked to interspecific competition between shrubs and annual crops. In fact, high shrub density implies an intense root network which leads to significant underground competition between shrubs and annual crops, particularly for water, which causes a reduction in the growth and survival of the interplant.

On the other hand, for a normal density (around 200 plants per hectare), the productivity of intercropping increases, whatever the climatic conditions of the year. Chriyaa and El Mzouri (2004) showed that the land equivalent ratio of barley and fallow production in alley-cropping increases respectively by 54% and 39% in comparison with management without shrubs.

Furthermore, tree alfalfa (*Medicago arborea*), a spontaneous shrub from the Mediterranean Basin particularly rich in protein (De Koning and Duncan, 2000), constitutes another agroforestry fodder alternative for Moroccan arid zones. The introduction of this shrub in association with barley or fodder species reduces the impact of periods of scarcity by improving fodder availability (El Koudrim et al., 2020). Indeed, *Medicago arborea* produces significant aerial biomass of good quality. This fodder is added to that produced by intercropping fodder crops and provides the element that is most lacking in the fodder resources of arid zones, namely nitrogen or total nitrogenous materials (TNM). Hamdi et al. (2019) reported TNM rates of 14.4% and Ventura et al. (1999) found values of 15.5%, relatively high values compared to our results (10.7%). On the other hand, *Medicago arborea* presents a relatively high level of mineral matter and low levels of wall constituents (Hamdi et al. 2019, Ventura et al. 1999).

The nutritional value of *Medicago arborea leaves* under the conditions of our research was found to be average to good with an average TNM rate of 10.7% and a digestibility of 70% on average (Table 2). These results are low compared to those found by De Koning and Duncan (2000), in areas with low rainfall in Australia for TNM, but remain close with regard to digestibility, the values they found for these two parameters are respectively 20% and 79%.

Table 2. Nutritional value of Medicago arborea foliage

	TNM (%)	DNM (%)	MM (%)	OM (%)	D (%)	DOM (%)	WORLD (%)	FU /kg DM
Average	10.7	6.4	10.1	89.9	0.7	63.81	26.1	0.72

UF/kg MS= (2.36 DOM-1.2 MOND) /1650 (Breirem, 1939); DNM (gr /kgMS) = 0.9294 TNM-3.52 (Demarquillyet Weiss, 1970); DOM (gr /kg DM): digestible organic matter = MOx d; MOND (gr /kg DM): indigestible organic matter = OM – DOM; d: Apparent digestibility coefficient of OM; DNM: Digestible Nitrogenous Matter; TNM: Total Nitrogenous Matter.

Medicago arborea plantations in alley cropping require well-reasoned management. Indeed, the period of occupation of the plots by intercropping coincides with the optimal period of exploitation of the shrub, which requires cutting the shrub and distributing it to the animals at the trough. The cutting height of 30 cm allows better regeneration of the shrub and good quality of the fodder. Concerning this last parameter, Al Masri (2013) concluded that cutting *Medicago arborea plants* at a height of 25 cm gives good quality fodder compared to the height of 50 cm.

On the other hand, it should be noted that the slowdown in the growth and development of *Medicago arborea plants* from the beginning of summer is accompanied by a fall of leaves, confirming the winter and spring growth character of this species. This leaf fall is attributed to higher leaf senescence during seed maturity (Lefi et al. 2003). This fact could be an indicator of the optimal period of exploitation of the foliage of *Medicago arborea* whether by direct grazing or by cutting and feeding at the trough. Moreover, Al Masri (2013) showed that the nutritional value of *Medicago arborea* decreases considerably in late summer and mid-autumn compared to winter and spring. The length of this period would depend on when the last rains stopped. But it should not extend beyond spring. And given that the foliage of *Medicago arborea* is exhausted quite early either by grazing, cutting or leaf fall, planting in juxtaposed plots or in the same plot of summer-growing shrubs, such as *Atriplex nummularia* , could constitute a solution that would provide animals with additional fodder in summer and fall. In addition, this mixed use of *Medicago arborea and Atriplex nummularia* could be a promising bio-saline agricultural technique to develop soils affected by salinization (Kurdali, 2010).

Cereal farming and agroforestry

Although irregular, rainfed agriculture is crucial for Morocco, which only covers 62% of its cereal needs (Badraoui and Dahan, 2011). While irrigated land, which covers 13% of arable land, is mainly dedicated to high-value production intended for export (Badraoui and Dahan, 2011), most cereals come from rainfed areas. Chaouia contributes greatly to national cereal production (Mrabet, 2011), with 15% of Moroccan wheat being produced in Chaouia (Fredenburg, 2012). Wheat and barley are considered the most important economic resource in drylands (Mrabet et al., 2012). In these two regions, crops are almost entirely rainfed, with only 3% of arable land being irrigated (ADA, 2013). 76% of Chaouia's arable land is used for crop production, including 96% for cereals (ADA, 2013).

Rainfed agriculture suffers from a number of limitations and constraints, resulting in limited cereal yields (Mrabet et al., 2012). In Chaouia, cereal yields are constrained by the dominance of the cereal-cereal rotation and the limited availability of suitable seeds (ADA, 2013).

Improving production has become a crucial priority in these areas. The association between perennial species and annual species commonly called agroforestry is an agricultural practice to be recommended insofar as it can improve crop production and preserve natural resources. Agroforestry therefore lends itself very well to the concept of ecoagriculture, through which we focus as much on the production of crops as on the conservation of the biodiversity of the natural environment.

The adoption of agroforestry constitutes a scientifically relevant and science-based approach to address the challenges posed by drought in the agricultural sector. It offers an integrated solution, based on ecological principles, to promote efficient, sustainable and resilient agricultural production in arid and semi-arid areas.

Barley is the most cultivated species in arid zones of Morocco. It is an annual plant with erect, robust stems growing in clumps and can reach 60 to 120 cm in height and a terminal spike can reach 20 cm in length. Grain, hay and straw are used for animal feed. The interest of barley lies in the fact that it can provide good winter fodder and at the same time produce grain on the regrowth after topping.

Figure 7 shows the barley grain yield in the alley cropping system. The Caroubier plot gave the highest yield in terms of barley grains, i.e. 22.4 q/ha, while the other two plots had lower yields, 16.3 q/ha for the Medicago plot. and only 6.5 for the argan tree. The biomass is relatively similar for the plots of argan (275 g/m², 2.75 tonnes/ha) and shrub alfalfa (290 g/m², 2.9 tonnes/ha), but that of the Carob tree stands out at again with significantly higher values (303 g/m², 3.03 tonnes/ha). Overall, the Caroubier plot seems to offer the best yields, particularly with regard to barley grain production.

Furthermore, the intermediate zone between the center and the trees (argan tree, carob tree and tree alfalfa) has the highest density, number of grains per ear and weight of 1000 grains and therefore the highest barley grain yield, followed by close by the middle area of the plot. While the area below the trees presents lower values for all measured parameters. Indeed, the intermediate zone being located far enough from the trees allows the barley to benefit from the good porosity created by the tree roots without suffering from shading. This promotes more vigorous growth of the barley and improves its yield. Additionally, competition between trees and the annual crop is also reduced, resulting in greater crop density (Figure 8).

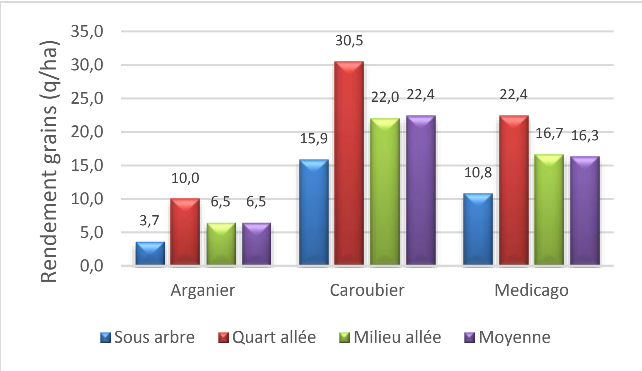

Figure 7. Grain yield depending on the distance from the tree

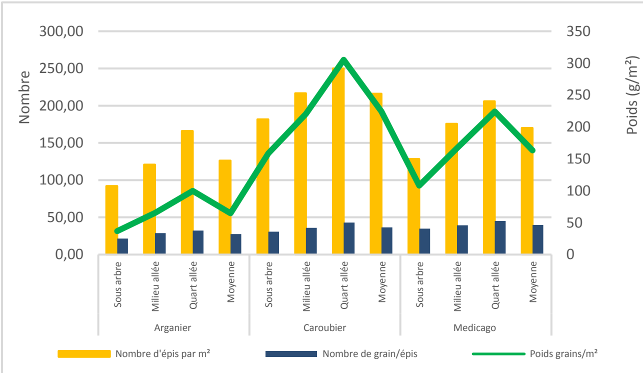

Figure 8. Performance parameters

Furthermore, in the agroforestry system based on olive trees, Daoui et al. (2021) showed that the introduction of the tree limited crop growth and yield, the reduction was around 33% for legumes and 47% for cereals. Furthermore, cereals (durum wheat, soft wheat and barley) negatively affected shoot elongation and olive yield. While legumes (fava bean and lentils) had no effect on olive growth and yield.

Similar responses were found when comparing crops at different distances from olive trees. Annual crops generally have lower biomass and yield, near trees compared to the middle of alleys, causing significant spatial heterogeneity in crops (Daoui et al., 2021).

On the other hand, the land equivalent ratio (LER), which provides information on the overall production of the plot, reached 1.36 with lentils and 1.33 with fava beans, the lowest LER was recorded with durum wheat with 1.01, and the highest LER with cereals was recorded with soft wheat and reached 1.19 (Table 3). Thus, despite lower crop yield than pure crops, LER > 1 reveal that olive agroforestry is a promising way to improve land and resource productivity, especially with appropriate crops and integration of legumes in the system.

Table 3. Land equivalent ratio of crops associated with the olive tree (Daoui et al. 2021)

Association	Olive-DW	Olive-Barley	Olive-Faba	Olive-lentil	Olive-Chickpea
LER	1.34	1.39	1.46	1.56	1.36
Gain %	34	39	46	56	36

Improvement of soil quality and agroforestry

Soil in arid areas is generally shallow and poor in organic matter, two characteristics that prevent water storage and therefore result in a limited water reserve. It supports a weak and precarious vegetation cover, further accentuating the phenomenon of desertification. And because of low rainfall, high evapotranspiration and low soil moisture retention, aridity manifests itself with even greater intensity as soil and water resources continue to degrade.

The introduction of trees and shrubs into cultivated land improves the quality of the soil. Indeed, the values of soil organic matter and carbon (C) increase in agroforestry plots based on atriplex and barley compared to those in barley monoculture (Table 4). The value of the OM is around 4.8% thanks to the introduction of *Atriplex nummularia*. However, a study in the semi-arid climate zone of Morocco found that 70% of soils are poor in organic matter and contain values ranging from 0.7 to 1.5% OM, especially in arid zones (El Oumlouki, et al., 2014). Agroforestry could therefore improve the fertility characteristics of the soil, in particular by improving its organic matter content.

Still regarding the effect of agroforestry on soil fertility, Daoui et al. (2021) found that the distance from the olive tree row has different effects on soil organic matter, the maximum organic matter content is recorded near the tree and is higher with legumes than with cereals.

In addition, the plots under the practice of AF have a soil richer in nitrogen than the monoculture plots (Table 4). Thus, proving that trees can provide nitrogen inputs in agroforestry systems either by biological nitrogen fixation (BNF) or by absorption of nitrogen leached in depth and nitrogen from leaf and root litter (Ganry and Dommergues ,1995). This is of great interest to farmers in arid regions of Morocco who face problems of “nitrogen *hunger* ” for cereal crops. The introduction of the tree into cereal crops can therefore be a natural and profitable remedy to combat this problem.
For leguminous species, Young (1995) showed that it would be very beneficial to practice agroforestry by combining trees and crops in the same plots, and found that in the context of a semi-arid climate the soil fixes 1.5 to 3 times more nitrogen with trees than without trees. Indeed, the fact that woody plants meet their needs partially by fixation reduces the depletion of the soil around their roots and makes more nitrogen available to associated non-nitrogen-fixing crops (Gillespie et al., 2000).

The association of *Atriplex nummularia* and Barley also shows an optimal C/N ratio of 9.66 in the first fifteen centimeters of the soil and 8.97 in the second, exceeding in both cases the monoculture soils (Table 4). These values allow good microbial activity and a good balance between humification and mineralization. So, using nitrogen-fixing trees and shrubs can create more favorable conditions by providing both organic matter and nitrogen to the soil.

In short, agroforestry constitutes an important supplier of goods and services for the environment as part of a context of integrated management of agricultural land and rural areas (De Baets et al., 2007).

Table 4. Soil quality in alley cropping and monoculture

	Horizon 1 (0 – 15 cm)				**Horizon 2 (15 – 30 cm)**			
	OM%	VS%	NOT%	C/N	OM%	VS%	NOT%	C/N
Barley	3.8	2.2	0.23	9.57	2.6	1.5	0.17	8.82
Atriplex + Barley	4.8	2.8	0.29	9.66	4.6	2.6	0.29	8.97

Conclusion

In an arid environment, the AF system offers good production and better quality, in particular, of fodder through improved water use efficiency and improved production and quality of intercrops (fallow and crops). In addition, it provides additional production (fodder, fruits and wood).

Additionally, agroforestry improves soil and water resources. It increases the OM rate of the soil and its C and N content, which allows it to better resist recurrent droughts and desertification and to better store water.
On an economic and social level, AF makes it possible both to maintain an annual income thanks to intercropping, and to build up valuable capital, with the trees.
Agroforestry therefore brings several benefits to producers, namely, increased yield and better quality production, diversification of products and activities, increased income and social development and subsequently enhancement of heritage for future generations. So it is necessary:

- To strengthen research on species associations (woody and herbaceous) to identify beneficial interactions and determine the suitable species and associations for each type of SAF.
- Conduct socio-economic research to determine the processes and conditions necessary to generalize the adoption of agroforestry, in order to resolve the problems of Moroccan arid zones, and thus guarantee the sustainability of agricultural activity in these areas.
- Adopt agroforestry practices on a large scale and plant trees on the lines and borders of agricultural plots to reduce evapotranspiration, ensure constant supplies of organic matter and mineral elements to the soil, limit the risks of its erosion and facilitate the water infiltration.

State commitment is necessary to create a social dynamic to encourage the adoption of agroforestry, through raising awareness among farmers and financing planting programs for croplands and rangelands.

Let's remember that there are always good years and bad years, the bad ones are likely to repeat themselves more frequently with climate change. It is important to prepare for it and adapt to it by implementing good practices that secure the production systems of Moroccan arid zones.

Bibliographic references

Agence pour le Développement Agricole (ADA), Région Chaouia-Ouardigha, 2013. http://www.ada.gov.ma/ListesRegion.php?Region=6.

Al Masri M. R., (2013). An in vitro nutritive evaluation of Medicago arborea as affected by growth stage and cutting regimen. Livestock Research for Rural Development, Volume 25, Number 5, May 2013.

Arif A., Tiedeman J., Chryiaa A., et Derkaoui M., 1994. Atriplex as forage for arid areas of Morocco: a review. Actes de la Conference sur les "Acquis et perspectives de la recherche agronomique dans les zones arides et semi-arides du Maroc". 24-27 Mai, Rabat, Morocco. p. 573-590.

Badraoui, M., & Dahan, R. (2011). The Green Morocco Plan in relation to food security and climate change. Food Security and Climate Change in Dry Areas. p. 61.

Bora, Z., Angassa, A., Wang, Y., Xu, X., et You, Y., 2021. Effect of elevation on the density and species composition of encroacher woody plants in Borana rangeland, southern Ethiopia. Environ. Manag. p. 1–13.

Boulal, H. 2001. Memoire de titularisation. INRA Maroc, non publié.

Boulanouar et Matthess-Guerrero, 1997. Morocco country paper. Global Agenda for Livestock Research. Proceeding of a Consultation on Setting Livestock Research Priorities in Western Asia and North Africa (WANA) Region. 12-16 November 1997. ICARDA, Alepo, Syria. p 96-102.

Burrows, W.H., 1993. Deforestation in savanna context-problems and benefits for pastoralism. In: Proceedings: XVII International Grassland Congress.

Chriyaa A. 2006. L'atriplex et le cactus comme suppléments à la paille dans l'alimentation d'agneaux en croissance. Rapport annuel 2005-2006 du CRRA Settat.

Chriyaa A. 2007. L'atriplex et le cactus dans l'alimentation des brebis en lactation nourries à base de paille de blé non traitée ou traitée à l'urée. Rapport annuel 2006-07 du CRRA Settat.

Chriyaa A. et El Mzouri E., 2004. Introduction des arbustes fourragers dans les systèmes de production en zones à faible pluviométrie. 1th meeting of the Mediterranean Forage Resources Sub-network of the FAO-CIHEAM inter-Regional cooperative research and Development Network on pastures and fodder Crops. Djerba, Tunisia. Vol. 62. p 203-206.

Daoui K., M. Fatemi, R. Razouk, A. Bouaziz, Barkkaoui et A. Amassghrou (2021). Optimisation de la production des systèmes agroforestiers : olivier – céréales – légumineuses. Rapport d'activité PRMT 2021-2024. INRA, Maroc

Daoui. K, 2012, L'agroforesterie ou l'art de combiner des arbres et des cultures, INRA Meknès Magazine, Publié le 17 avril 2014, par, Bahri N

De Baets, S., Poesen, J., Knapen, A., Barberá, G. G., & Navarro, J. A. (2007). Root characteristics of representative Mediterranean plant species and their erosion-reducing potential during concentrated runoff. Plant and Soil, 294(1). p. 169-183.

De Koning C.T. and Duncan A.J. 2000. Medicago arborea - a leguminous fodder shrub for low rainfall farming systems. In Sulas L. (ed.). Legumes for Mediterranean forage crops, pastures and alternative uses. Zaragoza: CIHEAM-IAMZ, 2000. p. 435-438: (Cahiers Options Méditerranéennes: v. 45).

El Koudrim M (2014). Impacts des actions anthropiques et des stratégies socio-foncières dans l'amplification de la désertification au niveau des Hauts Plateaux de l'Oriental. Edition Al Awamia, INRA Maroc.

El Koudrim M, Acherkouk M., Mahyou H., Maâtougui A., et Bouayad A., 2003. Dégradation du couvert végétal au Maroc Oriental. Journées scientifiques sur les parcours. Dakhla du 6 au 9 juin 2003.

El Koudrim M., 2021, Contribution à la gestion de l'intégration de l'agriculture et de l'élevage en milieu aride et semi-aride sous le système d'agriculture de conservation (dissertation doctorale, Université Hassan 1er de Settat, Maroc).

El Koudrim M., Laamari A., Acherkouk M., Chriyaa A., El Mzouri E. and Hilali S., 2020. Participatory evaluation of the degradation of El Hadra rangeland (Rhamna Province). African & Mediterranean Agricultural Journal (AFRIMED – AJ) Al Awamia (128). p. 62-75.

El Oumlouki et al., 2014 dans Benazzouz, I., Talbi, M., & Saber, N. Etat Environnemental Des Sols De La Region De Casablanca.

FAO (2020). Banque mondiale/FAO, fichiers électroniques et site Web de l'Organisation des Nations Unies pour l'alimentation et l'agriculture, Surface forestière (% du territoire) sur la période 1990- 2015.

Fredenburg, P. 2012. Conservation agriculture: opportunities for intensifying farming and environmental conservation in dry areas. ICARDA.

Ganry F.et Y. R. Dommergues (1995). Arbres fixateurs d'azote : champ ouvert pour la recherche. Dossier azote. Agriculture et développement n° 7.

Gillespie A.R., Jose S., et S.G. Pallardy (2004) Interspecific interactions in temperate agroforestry. Agroforestry Systems (61). p. 237-255.

Guitton, J-L. 2009 Ministère de l'agriculture, de l'alimentation, de la pêche, de la ruralité et de l'aménagement du territoire, Article dans Revue Forestière Française. p. 1-7.

Hamdi H., Majdoub-Mathlouthi L., et Kraiem K. (2019). Caractéristiques floristiques d'un parcours naturel amélioré par le Medicago Arborea dans le semi-aride de la Tunisie. Université de Sousse, Institut Supérieur Agronomique, BP 47, 4042 Chott-Mariem, Sousse, Tunisie.

Harbouze R., J.-P. Pellissier, J.-P. Rolland, et W. Khechimi. 2019. Rapport de synthèse sur l'agriculture au Maroc. [Rapport de recherche] CIHEAM-IAMM. p. 27-28-29.

Hartwig, U.A., 1998. The regulation of symbiotic N2 fixation: a conceptual model of N feedback from the ecosystem to the gene expression level. Persp. Plant Ecol. Evol. Syst. 1, 92e120.

Hulme, P.E., Pyˇsek, P., Jaroˇsík, V., Pergl, J., Schaffner, U., et Vil`a, M., 2013. Bias and error in understanding plant invasion impacts. Trends Ecol. Evol. 28. p. 212–218. https:// doi.org/10.1016/j.tree.2012.10.010.

Kahi, C.H., Ngugi, R.K., Mureithi, S.M., et Ng'ethe, J.C., 2009. The canopy effects of Prosopis Juliflora (Dc.) and Acacia tortilis (Hayne) trees on herbaceous plants species and soil physic -chemical properties in Njemps Flats, Kenya. Trop. Subtrop. Agro-ecosyst 10, 441e449.

Kurdali F., 2010. Growth and N2 fixation in mixed cropping of Medicago arborea and Atriplex halimus grown on a salt-affected soil using a 15N tracer technique, Journal of Plant Interactions, 5:1. p. 37-44.

Lahlimi Alami in Saidi, A., & Diouri, M. (2017). Food self-sufficiency under the Green-Morocco Plan. Journal of Experimental Biology and Agricultural Sciences, 5(Spl-1-SAFSAW). p. 33-40.

Lassau, S.A., et Hochuli, D.F., 2004. Effects of habitat complexity on ant assemblages. Ecography 27. p. 157–164.

Le Houerou, H.N. & Popov, G.F. (1981). An ecoclimatic classification of intertropical Africa. Plant Production and Protection Paper, No.31. Rome: FAO. 40 p.

Lefi E., J Gulõas, J Cifre, M Ben Younes and H Medrano, 2003. Drought effects on the dynamics of leaf production and senescence in fieldgrown Medicago arborea and Medicago citrina. Ann. appl. Biol. (2004), 144. p. 169-176.

Linst¨adter, A., Bora, Z., Tolera, A., et Angassa, A., 2016. Are trees of intermediate density more facilitative? Canopy effects of four East African legume trees. Appl. Veg. Sci. 19 (2). p. 291–303.

Ludwig, F., de Kroon, H., Berendse, F.,et Prins, H.H.T., 2004. The influence of savanna trees on nutrient, water and light availability and the understorey vegetation. Plant Ecol. 170, 93e105.

Ludwig, F., de Kroon, H., Prins, H.H.T., et Berendse, F., 2001. Effects of nutrients and shade on treeegrass interactions in an East African savanna. J. Veg. Sci 12, 579e588.

Magnan, N., Larson, D.M., et Taylor, J.E. 2012. Stuck on stubble? The non-market value of agricultural byproducts for diversified farmers in Morocco. American Journal of Agricultural Economics 94 (5). p. 1055–1069.

Mathakhuta, R., Steyn, C., le Roux, P.C., et al., 2019. Invasive species differ in key functional traits from native and non-invasive alien plant species. J Veg Science. p. 1–13. https://doi.org/10.1111/jvs.12772, 00.

McPherson, J.K., and G.L. Thompson. 1991. Competitive and allelopathic suppression of understory by Oklahoma oak forests. Bull. Torrey Bot. Club 99:293-300.

Menezes, R.S.C., Salcedo, I.H., et Elliott, E.T., 2002. Microclimate and nutrient dynamics in a silvopastoral system of semiarid northeastern Brazil[J]. Agrofor. Syst. 56 (1). p. 27–38.

Mitchell, R., Keith, A., et Potts, J., 2012. Overstory and understory vegetation interact to alter soil community composition and activity. Plant Soil 352, 65e84.

Mrabet, R. 2011. Effects of residue management and cropping systems on wheat yield stability in a semiarid Mediterranean clay soil. American Journal of Plant Sciences.

Mrabet, R., Moussadek, R., Fadlaoui, A., et Van Ranst, E., 2012. Conservation agriculture in dry areas of Morocco. Field Crops Research 132. p. 84-94.

Nafzaoui A. et Ben Salem H., 2002. Forage, fodder, and animal nutrition. pp. 190-210, in: P.S Nobel (ed). Cacti: Biology and uses. University of California Press.

Scholes, R.J., et Archer, S.R., 1997. Tree-grass interactions in savannas. Ann. Rev. Ecol. Syst. 28, 517e544.

Smith, W.K., et Hughes, N.M., 2009. Progress in coupling plant form and photosynthetic function. Castanea 74 (1). p. 1–26.

Sraïri, M. T., 2011. Le développement de l'élevage au Maroc : succès relatifs et dépendance alimentaire. Le Courrier de l'environnement de l'INRA, 60(60). p. 91-101.

Stricker, K.B., Hagan, D., et Flory, S.L., 2015. Improving methods to evaluate the impacts of plant invasions: lessons from 40 years of research. [J]. AoB PLANTS 7 plv028-plv028.

Tarhzouti O., B. Boulanouar et M. Sibaoueih, 2006. L'élevage ovin en bour défavorable!: caractéristiques, atouts et contraintes. Chapitre dans l'ouvrage « L'élevage des ovins au Maroc ». Edité par Boulanouar B. et R. Paquay. INRA 2006. p. 161-178.

Treydte, A.C., Heitkonig, I.M.A., Prins, H.H.T., et Ludwig, F., 2007. Trees improve grass quality for herbivores in African savannas. Perspect. Plant Ecol. Evol. Syst. 8, 197e205.

Ventura M.R., Flores M.P., et Castañón J.I.R. (1999). Nutritive value of forage shrubs: Bituminaria bituminosa, Acacia salicina and Medicago arborea in Etienne M. (ed.). Dynamics and sustainability of Mediterranean pastoral systems Zaragoza : CIHEAM Cahiers Options Méditerranéennes; n. 39. p. 171-173.

Young A., 1995. L'agroforesterie pour la conservation du sol, traduit de l'anglais par Michel Baumer, chapitre 3. p. 21.


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