Beyond Industrial Agriculture: A Case for Agroecology Adoption in Sefrou, Morocco's Semi-Arid Region

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Abstract

Modern agricultural practices, reliant on chemicals and non-renewable resources, have harmed the environment, public health, and the economy. This study proposes agroecology as a sustainable alternative, emphasizing traditional agricultural wisdom over conventional methods. However, there is limited research on implementing agroecology for food security in semi-arid climates like Sefrou, in the Fez-Meknes region, Morocco. To address this, surveys of local sellers and farmers were conducted to identify challenges to food security, and interviews with agroecology experts were held to gather relevant practices and advice. Findings reveal that agroecological principles, such as permaculture, are adaptable even for small-scale farms, suggesting the feasibility of a holistic system that coexists harmoniously with the environment. The study highlights the need to educate the local population about sustainable agricultural approaches, emphasizing soil health, water conservation, biodiversity preservation, and the careful use of chemicals. By integrating insights from local stakeholders, farmers, and experts, the study provides valuable recommendations for promoting a sustainable agricultural paradigm in Morocco's semi-arid regions. This perspective aims to guide policymakers, farmers, and stakeholders toward an environmentally friendly and economically viable agricultural future.

Keywords: Agroecology, Morocco, Modern Farming Systems, Permaculture, and Pesticides

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INTRODUCTION

Arid and semi-arid regions of Morocco that lie in the northeast, central-west, and southwest of the country are characterized by high solar radiation and evaporation rates, as well as severe water shortages with limited and unpredictable rainfall. Drought occurrences and excessive groundwater extraction have been common in these areas, causing limited and unpredictable supply of soil moisture and low soil quality (El Mourid and Karrou, 1996; Ibno Namr and Mrabet, 2004). The lack of soil moisture is exacerbated by constant high temperatures and evaporation rates, negatively impacting crop yields and production consistency. The semi-arid region of Fez-Meknes region, situated in the Northern Central part of Morocco, covers approximately 6% of the nation's total land area and contributes 15.2% to the national Gross Domestic Product (GDP), faces risks and uncertainties regarding resource availability. For instance, one of the most significant challenges in the region is water scarcity, characterized by erratic rainfall rates that lead to droughts and insufficient crop irrigation, which in turn causes crops to be more susceptible to certain pests and diseases. Other relevant challenges in the region include low content of organic matter in the soil and its high susceptibility to erosion. In fact, high temperatures increase evaporation rates, exacerbating water scarcity and soil quality issues.

Considering the direct and indirect effects of semi-arid and arid environmental conditions that farmers face in the region of Fez-Meknes, agroecology represents a durable farming strategy. Agroecological systems are designed to harmonize with the specific environmental conditions of the region. This is achieved by adapting practices to local conditions and traditional knowledge, while also emphasizing the efficient use of resources to prevent water waste, reduce reliance on synthetic inputs, and minimize soil erosion. Additionally, agroecology promotes biodiversity through the incorporation of diverse crop varieties and species, as well as by discontinuing production practices that are harmful to the environment and that rely on renewable local resources. Agroecology also views farm land as a complex system where ecological processes such as nutrient cycling, predator/prey interactions, competition, symbiosis and crop rotation occur. For instance, crops, animals, soils, and other factors optimize various processes, including organic matter accumulation and decomposition, water retention, nutrient cycling and pest regulation (Altieri and Toledo, 2005). In a similar way, increasing agroecosystem primary productivity involves enhancing photosynthesis, water capture, nutrient cycling and reducing the need for external (synthetic) inputs (Tittonell *et al.*, 2012). Although agroecology practices such as composting and the use of organic fertilizers enable farmers to reduce production costs by minimizing the need for chemical fertilizer purchases (Kassie *et al.*, 2009), these practices seem to have been replaced by industrial agricultural systems.

In this work, we mapped out agroecology projects and practices that are currently being implemented by farmers in the arid and semi-arid regions of Morocco in order to compile useful information that can encourage the implementation and hands-on training of agroecology practices. Our mapping effort focused on the city of Sefrou, a specific geographic area within the

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arid region. We employed a combination of field surveys, interviews with local farmers, and data analysis to compile comprehensive information. Throughout our research, we actively engaged with local stakeholders, including farmers, agricultural organizations, and experts, to gather valuable insights and ensure the relevance of our findings. Here, we provide a practical resource that encourages the widespread adoption of agroecology practices among farmers in the region.

Challenges for Sefrou Region

The province of Sefrou covers both the city and the countryside that surrounds it. It is located in the northern center of Morocco, and it is part of the Fez-Meknes region. Sefrou's south faces the beginning of the Middle Atlas Mountain, located in the center of Morocco, between the Rif and the High Atlas mountain. This mountain is oriented from the South-West to the North-East, it extends for over 350 km and can reach peaks of 3,000 meters.

Sefrou's area is watered by several streams and underground sources, Oued Aggay, is the most valuable surface water source; its variation is sensitive to precipitation, which in the Middle Atlas depends on altitude and exposure to cloud masses coming from North-West. However, since 1979, Aggay shows a regression of its surface flow (Idrissi *et al*., 2018). In addition, ground water availability is becoming insufficient to meet the agricultural, domestic and industrial needs of the region. The effects of water scarcity were analyzed by Idrissi *et al.* (2018), who created a climatogram for the wet period (1968/69-1977/78) and the dry period (1978/79-2007/08), during which Sefrou changed from a sub-humid to a semi-arid region.

In addition to Sefrou's production, Ben Khadda *et al.* (2021) evaluated the knowledge of farmers in this region. One of their results reports that 40% of farmers don't store pesticides in different rooms and for empty containers they either burn them, bury them, or throw them at the edge of fields or public dumps. In fact, the Poison Control Center of Morocco (CAPM) established 1451 cases of pesticide poisoning in 2015 (Ben Khadda *et al*., 2021). Unsafe pesticide handling is mainly attributable to farmers with low education and insufficient training; applying high amounts to increase production. Indeed, only 10% of farmers in Morocco apply fertilizers based on soil analysis results (Rhioui *et al*., 2023).

Understanding permaculture as an alternative approach to industrial agriculture: Principles, practices, and livable implications

This research points out agriculture opportunities in Morocco that could help adapt and prevent climate change and mitigate its consequences on social and economic factors, as well as highlights the importance of growing food using a resource-efficient approach. Permaculture is a branch of agroecology and a promising alternative to industrial agriculture; it focuses on the design of agroecosystems, placing permaculture as a possible link between agroecological research and theory and practical implementation in agriculture. Based on the ethical principles of caring for the earth, caring for the people and setting limits to consumption, reproduction, and redistribute surplus, permaculture is defined as a holistic design process for complex ecosystems, where the landscape and people interact mutually, providing food, energy, shelter, and other material and non material needs (Krebs and Bach, 2018; Ouali, 2021).

Since the essential goal of agroecology is to increase and protect biodiversity, it is expected that the more diverse an ecosystem is, the more likely it is to thrive in adversity (pests and diseases, climate variability, limited resources, and land degradation). Some practices aimed at increasing biodiversity include, but are not limited to, the importance of agroforestry, soil building strategies, whole farm water management and harvesting techniques, productive landscape, attention to microclimate effects driven by local and regional topography and vegetation, diversity, and spatial configuration (El-Hiary *et al.*, 2021; Ferguson and Lovell, 2014).

In specific, Morocco's small-scale farming faces uncertainties regarding income perceived, due to climate change, high input costs and low investment return. A transition from traditional agriculture to sustainable agricultural systems will bring benefits to livelihoods in rural areas, biodiversity and the conservation of ecosystems (Ouali, 2021). Additionally, this change will mitigate climate change in Morocco related to temperature rise, rainfall regularity decrease, sea level rise, water scarcity, droughts and desertification.

MATERIALS AND METHODS

To gain a comprehensive understanding of the food system of Sefrou's region and the impact of industrial agriculture and to explore the potential benefits of agroecology in local agricultural practices, a series of surveys and interviews were conducted. A total of 40 participants were surveyed in person within the municipalities of Sefrou and Fes. The interviews were conducted at the five square markets that serve as crucial food sources for the local population. Further interviews took place at the regional distribution center in order to gather specific details about the origin of these agricultural products.

No personal information was solicited, and participants were individuals aged 18 years or older, who were explicitly informed of the voluntary nature of their involvement. To ensure effective communication with all participants, the surveys were formulated and collected in Darija, the Moroccan Arabic dialect. To achieve a high level of accuracy in the translation process, a comprehensive guideline was developed and implemented throughout the research process. One crucial aspect of this guideline was the selection of a bilingual interviewer with professional fluency in both Darija and English. The individual was trained and provided with detailed information regarding the research objectives and the specific context associated with the surveys for the purpose of mitigating the risks of misinterpretation.

Additionally, a series of interviews were undertaken with Moroccan experts who specialize in industrial agricul-

ture and agroecology. These interviews primarily focused on permaculture initiatives. Individuals aged 18 years or older, who were leading these projects, were identified and interviewed online or personally. These on-site visits provided a more immersive understanding of the practices and, in certain cases, even involved participation in hands-on activities to gain firsthand knowledge of agroecology methods. A semi-structured interview data collection method was implemented using preset open-ended questions. The interview's guide was a schematic presentation of core questions with the specific topics to be addressed. The one-hour interview also allowed for follow-up conversation on interesting points in the context of agroecology and permaculture that were raised by the participants. The information gathered from the surveys and interviews was securely stored and imported into Nvivo, where a comprehensive qualitative examination was conducted employing a thematic analysis approach and a description-focused coding strategy.

RESULTS

Sefrou's produce supplies come from various regions, both within and outside the country. The information gathered from surveys has led us to recognize the city's reliance on external support to ensure food security. Despite Sefrou being located in an area with relatively ample water resources, it still requires assistance from different parts of the country. Water-intensive crops such as tomatoes, watermelons and melons, for example, are sourced from the southern regions where water scarcity is prevalent. These regions rely heavily on underground water sources, which pose serious environmental risks including aquifer depletion, ecological consequences and land subsidence.

Limited access to fresh produce is a challenge faced by the local population. The transportation of produce to Sefrou (Figure 1) contributes to a significant amount of fossil fuel consumption, resulting in greenhouse gas

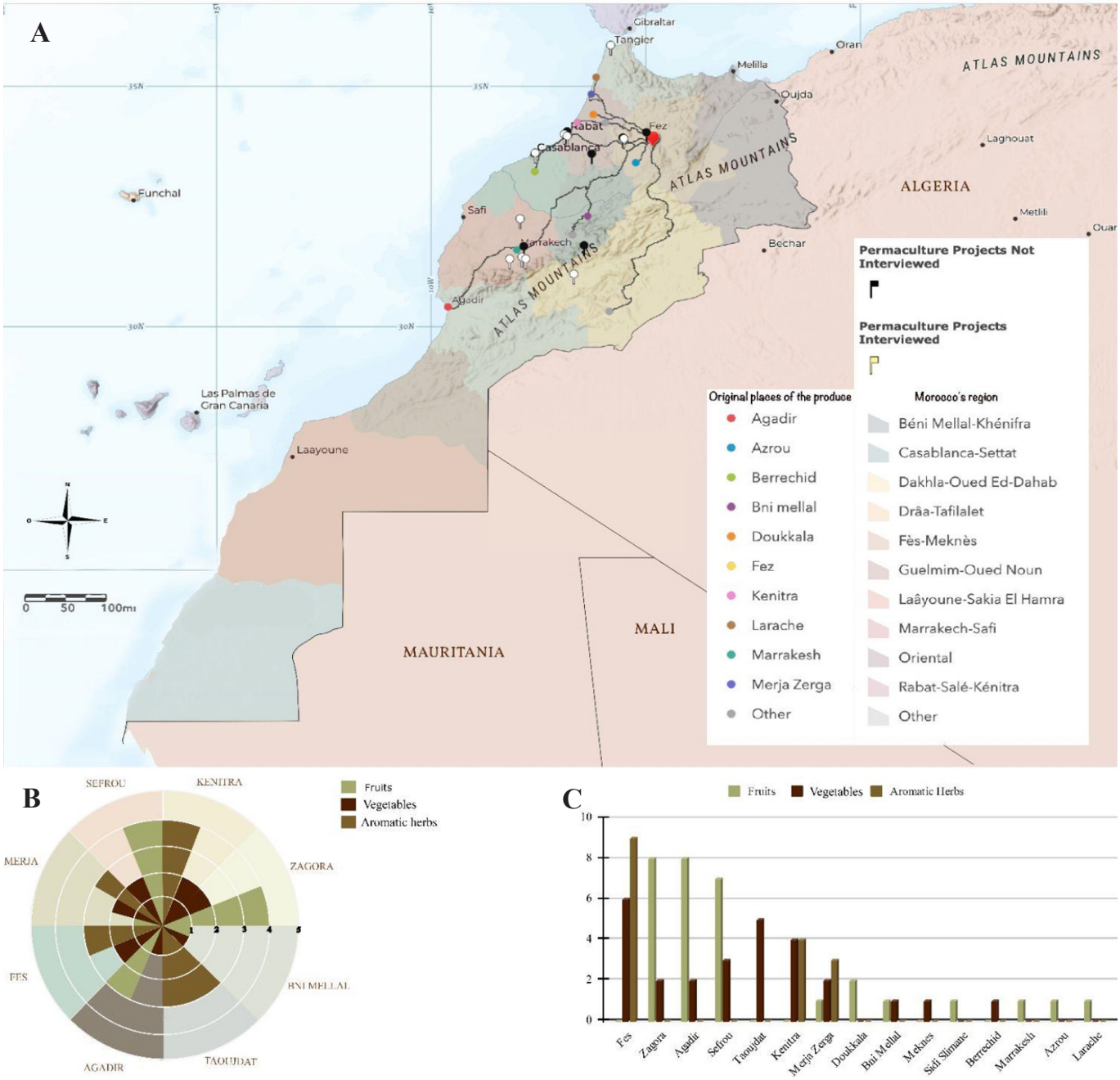


Figure 1: A. Food route map illustrating the journey of produce to reach Sefrou and agroecology projects in Morocco, B. Classification of produce based on the most frequently mentioned regions, C. Number of sellers associating specific regions with the same products

emissions. On top of that, the survey results revealed that 64% of participants sell produce sourced solely from industrial agriculture, 17.8% sell produce from a combination of industrial agriculture and direct farm supply and only 17.8% of sellers offer produce directly sourced from local farms.

Evidence-based recommendations and practical advice for transitioning towards agroecology

A number of good practices and advice were provided by professionals who work in the same weather and conditions as the area of Sefrou. All of them agreed with the fact that an agroecological field can reach the same production or even better and more diverse than industrial agriculture (Figure 2). Here are the most mentioned advice and good practices:

Soil

In order to optimize agricultural practices, it's crucial to consider several key strategies to preserve soil. During drought seasons, it's advisable to refrain from disturbing the soil extensively. For example, over tilling the land, which can cause rapid water evaporation, soil erosion and significant loss of topsoil. This can subsequently lead to reductions in both yield quantity and quality. To counteract soil erosion, nutrient depletion and loss of biodiversity, it's recommended to avoid leaving bare soil whenever possible. For instance, after the harvest, precautions should be taken to prevent livestock from consuming all yield remnants, a practice that can diminish organic matter and soil nourishment. In addition, embracing direct seeding (where seeds are sown directly into the ground) offers benefits such as reduced soil erosion, heightened soil biological activity and enhanced seed adaptation to local conditions, resulting in robust root systems and higher yield potential.

The production of compost presents a valuable opportunity to enrich and enhance soil fertility by yielding nutrient-rich soil and promoting natural plant growth, while simultaneously decomposing waste into a useful product. This recycling process involves the biological breakdown of organic matter under controlled and aerobic conditions by microorganisms. There are various composting methods, including Indian Bangalore Composting (a pit covered with organic residues and night soil for three months without turning or watering), Vessel Composting (conducted in an enclosed area), Windrow Composting (materials regularly turned and stored in long windrows), Vermicomposting (involving the use of earthworms to degrade organic matter), Static Composting (formation of a static pile of material with no turning), Sheet Composting (the spread of organic matter onto the soil as a mulch), Indian Indore Composting (organic matter collected into a high layer and often watered), and Berkeley Rapid Composting (a hot composting method where active management of the compost accelerates the decomposition of organic matter). Lastly, the application of mulching and crop covering proves advantageous in conserving moisture, suppressing weed growth, preventing soil erosion and bolstering overall soil fertility, especially when using nitrogen-fixing plants such as comfrey, clover and alfalfa.

Water

Harvesting rainwater stands as a fundamental approach. This practice involves capturing and storing rainwater for later use, reducing dependence on external water sources. In addition to harvesting, the construction of swales, shallow channels strategically positioned along the land's contour lines, proves highly beneficial. By capturing and redirecting water, swales effectively mitigate runoff, resulting in improved water conservation,

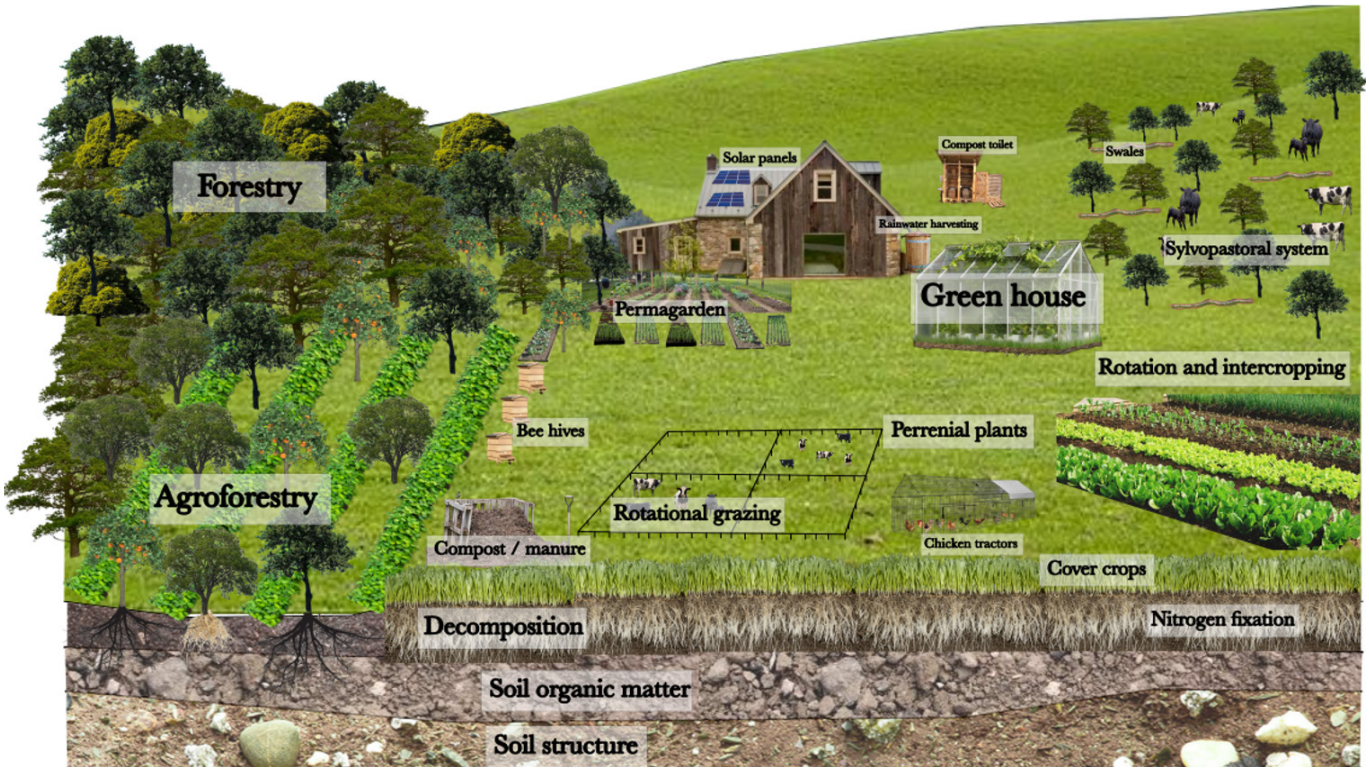


Figure 2: Illustration of a permaculture model for the Fez-Meknes region

regulated soil moisture, erosion prevention, heightened soil fertility and a more resilient landscape. Additionally, the adoption of gravity-fed drip irrigation presents a prudent solution for crop hydration. This system employs a network of small pipes equipped with emitters, delivering water directly to plant roots. Relying on gravity, this controlled irrigation method ensures a gradual and consistent water flow, promoting efficient utilization and minimal wastage.

Biodiversity

Integration of drought-resistant plants offers a promising solution to increase biodiversity. These plants possess the ability to conserve water resources while demonstrating resilience against diseases and pests. Notable examples of such indigenous species in Morocco encompass the Argan tree (*Argania spinosa*), Aleppo Pine (*Pinus halepensis*), Moroccan Thyme (*Thymus maroccanus*), Atlas Mountain Fig (*Ficus carica*), Desert Marigold (*Nephelium serotinum*), Prickly Pear (*Opuntia ficus-indica*), Moroccan Primrose (*Primula moroccanus*) and Atlas Mountain Poppy (*Papaver rupifragum*). It is prudent to cease from cultivating water-intensive plants in regions grappling with water scarcity.

Aside from integrating drought-resistant plants, the adoption of intercropping practices can enhance agricultural efficiency. Intercropping involves strategically planting different crops in close proximity, whether in alternating rows or within the same row. This approach offers potential benefits such as nutrient cycling, weed suppression, yield increases and risk reduction. As demonstrated in trials at the National School of Agriculture of Meknes, Morocco, companion planting such as corn and zucchini, onion and carrot, as well as combinations like corn and pepper, lettuce and tomato, carrot and pepper, parsley and turnip, onion and zucchini, eggplant and peas, and beet and peas are proved to work together in an efficiency way. In addition, the practice of seed saving in every successful production is the most favorable way of improving the next production by planting the seeds who are most adjusted to the growing zone.

Lastly, the construction of hedges emerges as a valuable strategy. They serve as windbreaks, shielding crops from harsh winds while also contributing to biodiversity enrichment and habitat creation, playing a crucial role in erosion control, stabilizing the soil and preventing its depletion.

Chemicals

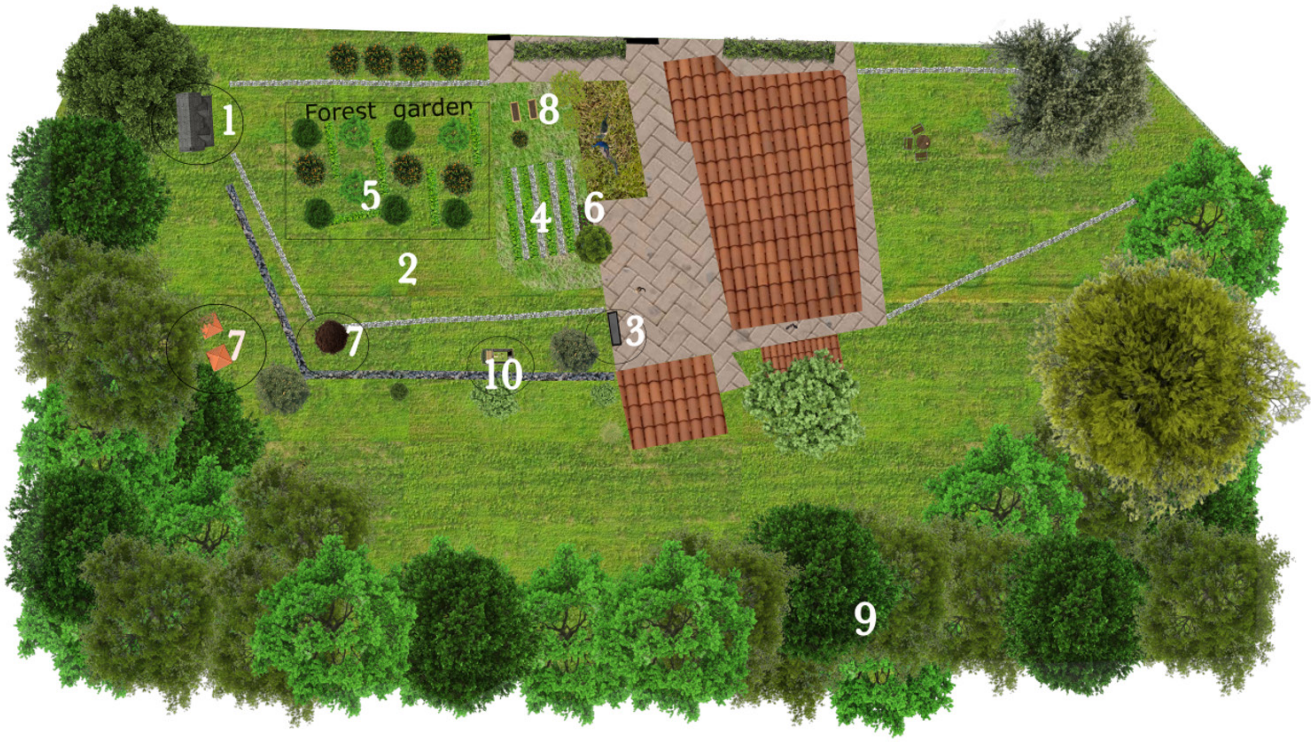
It is imperative to avoid excessive application of chemical products, fertilizers, or pesticides in fields because they do not necessarily lead to improved quality of yield. Instead, they can have adverse consequences, such as direct pollution of soil, water and vegetation. In contrast, the incorporation of organic fertilizers such as composting and liquid plant manure is an alternative way of leverage with animal waste, organic matter and resources already available at the farm. In addition to organic fertilizers, the adoption of Integrated Pest Management (IPM) presents a judicious approach to pest control that minimizes detrimental effects on the environment and human well-being. IPM is centered around sustainable, long-term pest prevention and encompasses a range of strategies, including pest monitoring, prevention, cultural controls, biological controls, mechanical and physical interventions and chemical control as a last resort. Regular evaluation and adjustment are key to maintaining its effectiveness. Lastly, harnessing livestock manure as organic fertilizer holds significant value. This resource contains vital nutrients such as Nitrogen, Phosphorus and Potassium, essential for plant growth. Additionally, manure organic matter content enhances soil structure and fertility.

Advices

Farmers can initiate a progressive journey into agroecology through gradual experimentation on a segment of the farm (Figure 3), allowing meticulous assessment of the efficacy of the practices implemented. Aside from implementing agroecology, it is recommended to promote partnerships between farmers, researchers, civil society organizations and governmental institutions. This collaborative synergy facilitates the exchange of knowledge and the dissemination of best practices, inciting the evolution of agroecological methods. In addition, this collaboration will empower individuals by providing accessible avenues to training and educational programs focused on agroecological principles, catering to both farmers and students alike. These initiatives lay the foundation for informed and skilled practitioners. Partnership and networking are important, as well as encouraging the government to be a supportive environment by implementing financial incentives and agricultural policies that defend the adoption of sustainable agroecology practices. This strategic alignment ensures that sustainable methods are not only encouraged but economically viable. Lastly, raise public consciousness by amplifying awareness regarding the countless benefits of agroecology. Through targeted outreach and education, foster a growing demand for organic and sustainable agricultural products, thus motivating responsible consumption and production.

CONCLUSION

The majority of food in Morocco is supplied by industrial agriculture, which has a significant presence in the Moroccan markets. Over the years, the country has witnessed a shift towards larger-scale agricultural production. Sefrou's self-sufficiency is getting replaced by industrial production, where the local farmers are being led to get into an inequitable competence with massive production companies. This shift can be seen in the local market, where the daily basic produce comes to the city from different regions in the country. Sometimes and depending on the product, they can come from places outside Morocco. Still, traditional and small-scale produce plays a role in the production and Sefrou's market still hosts a few local sellers.



Permaculture principles	Permaculture features									
	1. Learning center	2. Cover crops	3. Irrigation method	4. Row cropping	5. Forest garden	6. Herbal garden	7. Compost and compost toilets	8. Raised vegetable gardens	9. Hedge	10. Chicken house
Observe and interact	x			x	x	x	x	x	x	x
Obtain yield				x	x	x	x	x	x	
Self regulation and accept feedback	x	x		x	x		x	x	x	
Renewable resources/services				x	x	x	x	x		x
Produce no waste							x	x		x
Design from pattern to detail	x		x	x	x	x		x		
Integrate rather than segregate		x	x		x	x	x	x		x
Small slow systems	x	x	x		x	x	x	x		x
Use and value diversity		x			x	x		x	x	x
Use edges and value de marginal					x		x	x		
Use and respond to change	x				x			x		

Figure 3: Permaculture principles applied in a farm located in Sefrou

1. *Facility with dedicated places and classrooms for courses, workshops and discussions with learning materials and guidance*
2. *Plants that are grown primarily to improve soil health, enhance nutrient availability, prevent erosion, suppress weed, and add organic matter to the soil*
3. *Drip irrigation method that delivers river water directly to the plant roots, minimizing water loss.*
4. *Crops planted in straight lines to organize and maximize plant growth*
5. *Mimics the structure and functions of a natural forest ecosystem while providing a variety of edible plants*
6. *Dedicated space devoted to growing a diverse group of medicinal plants*
7. *Natural process that breaks down organic matter into nutrient rich organic material that can be used as fertilizer*
8. *Planting area is raised above the ground level in beds or containers. Beds filled with compost ideal for plant growth*
9. *Row of planted shrubs and trees to form a barrier, which acts as windbreaks, property line, and wildlife support*
10. *Shelter for chickens with purpose of pest control, fertilizer production, soil improvement, and egg production*

Sefrou's regional agricultural production is characterized by a semi-arid to arid climate where limited water resources, protection of the topsoil and efficient water management practices are crucial. Its production focuses especially on cherries. Well suited crops to dry conditions such as olives and almonds trees and some citrus, vegetables and fruits that require a careful irrigation method are part of the town's production as well. To achieve food security, Sefrou, like many other regions in the country, relies on other regions and importation. Nearby regions, distribution networks, supply chains and importations bring most of the fruits, vegetables and grains to the Sefroui's table. Zagora and Agadir, situated at distances of 623 km and 777 km from Sefrou, along with neighboring areas like Fes, Meknes and Taoujdat, serve as primary suppliers of agricultural produce to the city. Relying on external sources for produce brings to Sefrou and the region disadvantages such as: vulnerability to supply disruptions, economic dependence, unavailable quality of fresh products, environmental impacts, and a loss of support for local farmers. Furthermore, the massive agricultural production relies primarily on monoculture and chemical inputs which lead to a negative environmental impact, biodiversity loss, resource intensity (water, energy, and land), climate change, health and animal welfare concerns and economic impact on small farmers.

However, In order to mitigate these negative impacts associated with industrial agriculture, agroecology emphasizes the integration of ecological principles and local knowledge to create a resilient farming system. Due to the arid climate of the region, prioritizing practices that center around soil preservation, efficient water usage and sustainable land management becomes crucial. Agroecology and permaculture are known and practiced in Morocco either by farmers who are unaware of the term, or by specialist and trained farmers aiming for environmentally conscientious production and minimizing their footprint. Those farmers who implement in their fields traditional knowledge and practices that have been passed down through generations are using practices commonly adapted to the climate conditions of their lands.

Nevertheless, agroecological practices in Morocco lack comprehensive documentation, thereby constraining the dissemination of knowledge among local farmers. Therefore, this research endeavored to compile some of the most common practices within the projects interviewed. The foundational practices and principles provided here stem from the insights of farmers who have already embraced these approaches. The spectrum of agroecological practices includes **(i) water management**, prioritizing water harvesting techniques such as swales, terracing and rainwater collection; **(ii) Drought-tolerant plants**, including native plant varieties who can thrive with minimal irrigation; **(iii) Mulching, minimal tillage**, cover cropping, and composting, which replace the use of fertilizers and supplies the soil with organic matter, fertility, and nourishment conservation; **(iv) Companion planting**, where compatible plants are strategically placed together to provide mutual benefit; **(v) Food forest design**, by integrating trees to crops, particularly Nitrogen fixation; **(vi) Seed saving**, by collecting, storing and replanting seeds who were successful in the last harvesting. This practice will preserve and propagate locally adapted seed varieties and maintain plant diversity; **(vi) Crop rotation**, where seasonally the crops will be rotated in order to prevent soil depletion and control pests naturally. Furthermore, it is imperative to customize agroecology to local circumstances. For instance, Sefrou's arid conditions especially require strategies such as drought-tolerant plants, natural - shade, windbreaks, gray water recycling, and water harvesting techniques.

The adoption of permaculture design and practices provide multifaceted benefits for the environment, economy and social dimensions. By embracing permaculture, the health and productivity of the land is enhanced in parallel with the conservation of natural resources by creating resilient ecosystems. Permaculture embodies a collaborative and solidarity-driven movement, fostering a symbiotic relationship between the land and humanity, with the core principle of knowledge sharing. Its design mimics natural ecosystems while meeting human needs. By imitating natural ecosystems, the system tends to be more resistant, lacking the needs of external inputs such as fertilizers and pesticides. Moreover, incorporating diverse planting crops, composting, cover crops and mulching attract beneficial insects, improves soil health, and reduces the risk of crop failure. Above all, in order to create a permaculture design specific characteristics of the site and goals have to be taken in consideration. As a summary, transportation, energy, waste, design, access to land, site selection, permaculture site assessment and base map are some of the crucial steps to consider in the creation of the permaculture design.

REFERENCES

Altieri, M., Toledo, V. (2005). Natural resource management among small-scale farmers in semi-arid lands: building on traditional knowledge and agroecology. *Annals of Arid Zone*, 44: 365.

Ben Khadda, Z., Fagroud, M., El Karmoudi, Y., Ezrari, S., Berni, I., De Broe, M., Behl, T., Bungau, S. G., Sqalli Houssaini, T. (2021). Farmers' knowledge, attitudes, and perceptions regarding carcinogenic pesticides in Fez Meknes region (Morocco). *International Journal of Environmental Research and Public Health*, 18: 10879.

Ferguson, R.S., Lovell, S.T. (2014). Permaculture for agroecology: Design, movement, practice, and worldview. A review. *Agronomy for Sustainable Development*, 34: 251–274.

Ibno Namr, K., Mrabet, R. (2004). Influence of agricultural management on chemical quality of a clay soil of semi-arid Morocco. *Journal of African Earth Sciences*, 39: 485–489.

Kassie, M., Zikhali, P., Manjur, K., Edwards, S. (2009). Adoption of sustainable agriculture practices: Evidence from a semi-arid region of Ethiopia. *Natural Resources Forum*, 33: 189–198.

Krebs, J., Bach, S. (2018). Permaculture-scientific evidence of principles for the agroecological design of farming systems. *Sustainability*, 10: 3218.

Rhioui, W., Al Figuigui, J., Lahlali, R., Laasli, S.-E., Boutagayout, A., El Jarroudi, M., Belmalha, S. (2023). Towards sustainable vegetable farming: exploring agroecological alternatives to chemical products in the Fez-Meknes region of Morocco. *Sustainability*, 15: 7412.

Tittonell, P., Scopel, E., Andrieu, N., Posthumus, H., Mapfumo, P., Corbeels, M., Van Halsema, G. E., Lahmar, R., Lugandu, S., Rakotoarisoa, J., Mtambanengwe, F., Pound, B., Chikowo, R., Naudin, K., Triomphe, B., Mkomwa, S. (2012). Agroecology-based aggradation-conservation agriculture (ABACO): Targeting innovations to combat soil degradation and food insecurity in semi-arid Africa. *Field Crops Research*, 132: 168–174.

Idrissi, B. E. F., Cherai, B., Hinaje, S., Mehdi, K. (2018). Climatic variability and its influence on water resources in the northern part of the Middle Atlas Moroccan: the case of the Sefrou and the Anoceur Causses. *LARHYSS Journal*, 32: 155-179.

Ouali, H. (2021). Permaculture, a way to improve small family farmers livelihood in rural areas? Master's thesis, Estonian University of Life Sciences.

Masnat El-Hiary, Boubaker Dhehibi, Omama Al Hadidi, Malek Abo-Roman, Ala Abdallat, Majdy Adwan, Ala Awaideh (2021). Permaculture design and business plan for sustainable livelihoods programming: low-cost, sustainable solutions for food and nutrition insecure agro pastoral communities in Jordan. International Center for Agricultural Research in the Dry Areas (ICARDA), Lebanon.

El Mourid, M., Karrou, M. (1996). Agriculture in arid semiarid regions of Morocco: Challenges and prospects. *Al Awamia*, 92: 69-81.