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Morocco's agricultural sector is fundamental to the country's well-being yet faces increasing stress from climate change. Digital technologies for agricultural applications, referred to as agtech, are a pathway to climate-resilient agriculture, allowing for greater precision in farming. The transition to agtech is particularly challenging on small farms. Wider implementation of agtech in Morocco will require targeted government investment and cooperative programming among groups of large and small farms.

Introduction

Agtech, sometimes referred to as Agriculture 4.0, entails the digitalization of agricultural practices to increase productivity, minimize resource input, and adapt to climate change (El Moutaouakil et al., 2022). Morocco currently faces problems of climate change and water scarcity to which digital agriculture presents an attractive response, but feasibility of digital technology in Morocco, where farming plays a vital role in the economy and collective identity, remains a question. This article describes the agricultural applications of digital technology, addresses its current accessibility and challenges to broader implementation in Morocco, and concludes with recommendations for its widespread adoption in Morocco.

Background

Morocco is experiencing disproportionate effects of climate change. Although the global elevation in average temperature per decade has been 0.15°C, Morocco has seen a rise of 0.5°C each decade since 1970. With these temperatures come environmental concerns, including erratic weather patterns, declines in biodiversity, rising sea levels, and greater disease in plants and animals, all of which are detrimental to agriculture. Specifically, climate change is causing Morocco to experience decreased precipitation, putting the country in a precarious situation regarding water scarcity. By 2100, annual precipitation in Morocco is anticipated to decline by 10% to 40% (World Bank, 2019). Drought has had an impact on agricultural production in four of the past five years (Food and Agriculture Organization, 2023, July 26). In 2022, Morocco experienced the largest decrease in agricultural production in Africa, with a cereal output 60% below its five-year average as a result of drought conditions (Food and Agriculture Organization, 2023, March 6).

A significant portion of Morocco's agriculture, specifically in the southern regions, occurs in oases, which suffer intense impacts from climate change. Moroccan oases are projected to have a rise in average temperature of 2.2°C between 2020 and 2050, well above the Intergovernmental Panel on Climate Change warning of a 2°C increase limit (Adraoui & Jaafar, 2023). With these oases continuing to be hubs of civilization in the desert, their water demands will grow alongside their populations, directly conflicting with decreasing precipitation and more frequent drought, creating stress on agriculture in these crucial microclimates.

Morocco is classified as a water-scarce country and is predicted to reach the status of "absolute water scarcity" by 2030, meaning the country will have access to less than 500 cubic meters of water per person per year. Morocco's Economic, Social, and Environmental Council projects that the country will lose 80% of its usable water resources by 2045 (Hill & Pimentel, 2022). Agriculture in Morocco accounts for 86% of the country's water usage (El Hachimi, et al., 2021). Most of this consumption comes from irrigation activities. However, a significant portion of this water is wasted because of inefficient irrigation techniques and systems. In addition to general water loss is the issue of water contamination caused by agriculture. Underground aquifers contend with nitrate pollution from fertilizer runoff, which can lead to eutrophication in water bodies. Additionally, excess herbicide and pesticide runoff, which are health hazards, can leach into water supplies (Hill & Pimentel, 2022).

In Morocco, agencies and programs exist to combat water scarcity by advocating for water-saving techniques. For example, water resource information must be publicly available to increase transparency and water use efficiency (European Training Foundation, 2021). Additionally, regulations and restrictions are in place, such as banning cultivation of certain water-intensive crops (Adraoui & Jaafar, 2023). These efforts have been successful, and until now Morocco has been able to maintain overall water security. Yet, the country still faces climate-related challenges that demand constant reevaluation and stronger conservation efforts to protect its remaining water resources.

Current agricultural landscape

Agriculture is one of the largest sectors of Morocco's economy, accounting for nearly 13% of its GDP (International Trade Administration, 2024). Approximately one-third of all Moroccans are employed in agriculture, making the success of this industry fundamental to their collective well-being and the overall economy (Galal, 2023). In rural areas, agriculture is even more essential, with 80% of the labor force in rural regions employed solely in that sector (World Bank, 2019). With 43% of Morocco's population living in rural areas, the agricultural sector has a direct impact on the lives of a significant regional portion of Moroccans (Ghanem, 2015).

In Morocco's agricultural sector, there are two types of farms: larger, industrial farms, which export mainly to national and international markets, and small farms, with goods primarily for personal, family, and local consumption. Approximately 70% of all farms in Morocco are under five hectares in size and classified as "family farming," meaning they are managed by members of a family and rely mostly on nonwage family labor (Ghanem, 2015). A significant portion of Moroccans are smallholders, but the country as a whole is affected by large farms in regard to GDP and economic growth—both types of farms are integral to Morocco.

Agricultural extension agencies are a crucial resource, providing farmers with education, training, and development of skills and technology that boost efficiency, yields, and profits. Morocco has a network of decentralized extension agencies under the remit of the *Direction de l'Enseignement, de la Formation et de la Recherche* (*DEFR*) (Directorate for Education, Training, and Research). The mission of the extension system is to be "capable of simultaneous integration into the national agricultural strategic priorities and rural development," disseminating "new technologies of crop and animal production for sustainable development" and coordinating "extension activities through the decentralized mechanism and to develop knowledge of rural needs and environment." To meet these mission goals, there are regional offices, which provide training to farmers and are accessible to those in remote areas. There are also specific extension offices for irrigated versus rain-fed areas to focus on the specific needs of each region (Qamar, 2013).

Although Moroccan extension services do offer support to farmers, they have shortcomings that limit their effectiveness. In some cases, their ability to disseminate new agricultural technologies is limited due to inadequate relationships between national and regional staff. Additionally, the relationships among research, education, and extension institutions are weak (Qamar, 2013). Extension offices are often staffed by employees not trained to operate digital technologies, with most having graduated university more than 20 years prior, and there are no continuing education programs. Because of these shortcomings, only 11% of extension workers' time is spent on technology transfer actions. Extension offices are also confronted with a lack of financial resources, further hindering their ability to effectively help farmers in their region (Bilali et al., 2013).

A significant shortcoming of extension agencies in Morocco is the marginalization of women. In Morocco, 48.18% of women are employed in agriculture (Trading Economics, 2024b). Women account for 23% to 35% of labor on family farms, and this number is growing (Ghanem, 2015). Although women work in agriculture, they do not receive the same level of governmental and nonprofit assistance as men. Agricultural extension agencies in Morocco generally are staffed by men. Due to this gender inequity, the specific needs and cultural position of women often are not considered when extension programs are designed. These gender disparities lead to extension offices supporting less than 10% of rural women (Bilali et al., 2013). Additionally, women are not given many opportunities to express their input, causing women in rural areas to lack significant access to extension agencies' services (Ghanem, 2015).

There are three main agricultural education institutes in Morocco: Hassan II Agronomic and Veterinary Institute, National School of Agriculture of Meknes, and National Forestry School of Engineers of Salé. The Green Morocco Plan, a national strategy launched in 2008 in response to a food crisis, with the purpose of investing in and strengthening

Moroccan agriculture, created the Polytechnic Pole of Higher Agricultural Education to organize these three institutions into a group (Ministry of Agriculture…, n.d.-a). The Polytechnic Pole's mission statement includes "promoting innovation & entrepreneurship for value creation in [the] AgriTech sector" (*School of Agriculture…,* n.d.). Recently, Mohammed VI Polytechnic University launched an agriculture laboratory in partnership with the Abdul Latif Jameel Poverty Action Lab located at MIT in the US to research agricultural technologies designed to improve food security, profits, and productivity of smallholders. The laboratory will also work to lower barriers these farmers face in setting up and maintaining newer agricultural technologies (Rahhou, 2023).

Agricultural vocational training plays an important role in farmer education. Morocco has 12 regional centers and 53 local establishments that comprise its vocational training system. The establishments are scattered throughout the country, focusing mainly on rural farming areas: plains, mountains, and oases. Between 2008 and 2019, there have been 65,000 graduates, with an annual accommodation capacity of 6700, studying either agricultural sciences or farm management. Students study 70 sectors at various levels (ranging from apprenticeship to specialized technician) and topics like rural hydraulics and irrigation, field crops, and agricultural mechanics (Ministry of Agriculture…, n.d.-a). These agencies and institutions are integral to disseminating new knowledge and technology to farmers. Extension offices and vocational training sites must work in collaboration with research and development (R&D) institutions, as they depend on each other to advance research and ensure that those advancements are placed in the hands of farmers.

Digital technology in agriculture

Since the 1990s, Morocco has advanced toward a digital society in all sectors, not only agriculture (Elhazziti et al., 2023). The 2009 Digital Morocco Plan set a goal of digitizing 50% of all administrative procedures and bills, connecting 20% of Morocco's small and medium enterprises and establishing Morocco as a digital hub by 2020 (World Bank, 2019). The plan saw some success, aiding Morocco's participation in many international agreements and propelling the country into digital relevancy. Following the Digital Morocco Plan, the country launched a series of initiatives to further its transition into a digital hub. As a result, Morocco has become a leader in Africa for digital development, currently ranking eighth in digital competitiveness among the Middle East and North Africa countries (Elhazziti et al., 2023). In the area of agriculture, digital technology holds promise.

Digital technology can dramatically improve the efficiency of agriculture by complementing the personal care, knowledge, and attentiveness of traditional agriculture with the speed, ease, and scale of modern agriculture. In any agricultural field, although there is an inherent variability across individual plants, almost inevitably they are treated as though they are all "average." This approach often leads to over- or under-applications of water, fertilizers, pesticides, and herbicides (National Institute of Food and Agriculture, n.d.). Agtech can collect data to simplify decision-making, allowing for specific crop treatment and saving time and resources for farmers (Jabir & Falih, 2020). Utilization of these technologies has the potential to address issues that climate change places on agriculture and to grow food in an environmentally and economically sustainable manner. Maria Claudia Pachon, a senior digital development specialist, has stated that "[t]he shift to digital technologies will move the sector from resource-intensive agriculture toward precision farming, helping it respond as much to the demands of market competition as to the challenges of adapting to climate change" (World Bank, 2020). Applications of digital technology related to climate change in Morocco address areas like irrigation, pest and weed control, and fertilization.

Irrigation is one of the most crucial applications of agtech in Morocco. Digital technology allows for precise and efficient irrigation, maximizing productivity of the water used and decreasing water consumption. The Internet of Things, which combines sensors, processing capability, and networking software, is an optimal technology for delivering water to crops (Villalba & Abd Elkader, 2020, p. 5). Sensors that measure soil moisture, humidity, and temperature dramatically enhance decision-making for irrigation. Such systems take into consideration real-time weather to determine exact water needs and to adjust irrigation schedules and amounts accordingly, keeping up with increasingly erratic weather patterns.

As climate change progresses, crops become vulnerable to diseases, pests, and weeds. Climate change causes migration of species to ecosystems they previously did not occupy, introducing new diseases and invasive species to agricultural fields; thus, it is more crucial than ever to monitor and contain these threats. Sensor networks collect, com-

pile, and analyze data to enable rapid detection of the presence of disease and pest invasions and output instructions for specialized treatment of crops. Variation in pest attacks, weeds, and soil conditions, even within small areas, necessitates specific analysis and treatment. Traditionally, herbicides and pesticides are applied to an entire field, adding to costs for farmers and generating runoff that harms surrounding ecosystems (Subeesh & Mehta, 2021). Agtech allows for precise treatment, with fewer materials used and improved response times.

Fertilizer is a significant source of financial and material waste for farmers; excess application can harm neighboring ecosystems. Applying a precise amount of fertilizer can benefit financial and environmental sustainability of agriculture with more productivity per unit. Without digital technologies, soil testing can be a tedious, elongated process, requiring external laboratory testing, and one that is unable to account for soil differences across small changes in location on the plot of land. Sensor networks, however, quickly collect data, which feed into artificial intelligence models that generate predictions and decisions for creating a precise fertilization plan (Subeesh & Mehta, 2021).

Agtech can aid in addressing the puzzle of "cultivating the precise crop at the precise time" (Villalba & Abd Elkader, 2020). With climate change causing volatile weather patterns, digital technologies can be useful tools in monitoring weather data to make informed and strategic real-time decisions based on atmospheric changes, precipitation, and temperature, to determine precisely what, where, and when to plant, thereby increasing overall agricultural yield (Villalba & Abd Elkader, 2020). Understanding precise soil conditions, changing plant threats, and precipitation levels helps mitigate the risk of planting the wrong crops or at the wrong time, which can be detrimental for small farmers who depend on each year's yield for food and income. With better yield and reduced risk, agtech can open doors for small farms to boost profit and move into the category of the agricultural middle class.

Accessibility of digital agriculture

Morocco is introducing digital technology slowly and inequitably in agriculture. Not every farmer has equal access. A key step in analyzing the accessibility of digital technology to farmers in Morocco is considering how prevalent it is in the country overall and what programs exist to promote its spread to small farms. These factors determine the proper steps to expand usage of agtech.

Current scope of agtech

At present, Morocco is sitting at a point between traditional and modern agriculture, hoping to transition to Agriculture 4.0 (World Bank, 2019). Agtech is certainly present and gaining traction but is not widespread, and many farmers are not yet using it, especially those on remote, smaller farms. The Moroccan government is pushing expansion of digital technologies to build resilience in the agricultural sector, with robust, industrialized yields. Generation Green, created in 2020, is a plan intended to correct the flaws of the Green Morocco Plan, which had focused too much on industrial agriculture at the expense of neglecting smaller farms. This plan lays out a strategy for Morocco's agriculture sector, from 2020 to 2030, in hopes of supporting farmers, increasing yield, and becoming resilient to climate change. Generation Green focuses on establishing an "agricultural middle class," consisting of between 350,000 and 400,000 households, by encouraging high-value agriculture through support to young entrepreneurs (International Trade Administration, 2024). One of Generation Green's goals is to improve the quality of production, by adapting to technological trends. The plan states that R&D investments will almost double to better disseminate agricultural technology (Ministry of Agriculture..., n.d.-b). Generation Green makes it clear that farmers utilizing digital technology will contribute to resource sustainability by allowing for precise application of water and treatments. Such a prominent plan putting digitalization at its forefront is a strong indicator that there is a push to implement these technologies in Morocco along with official plans to ensure its outreach.

The Moroccan agriculture sector is augmenting its support of digital technologies, including expanding satellite imagery. The databases used most widely are Crop Growth Monitoring system, National Agricultural Registry, and FERTIMAP (Fertility Map of Cultivated Soils in Morocco) (World Bank, 2019). Additionally, digital management services are provided to larger cooperative and producer associations to be disseminated to farms. The COVID-19 pandemic catapulted Moroccan agriculture into digitalization of information transfer, education, trade, and communication. Agricultural education institutions are also playing a large role in the development and dissemination of agtech in Morocco. In 2003, the National Institute of Agricultural Research established networks to provide seven regional and three central sites with internet coverage, an infrastructure that supports digital technologies (Qamar, 2013).

Extending agtech to small farms

At present, digital technologies are used mostly on larger industrial farms, with smallholders tending to stick to traditional methods of agriculture (European Training Foundation, 2021). As the size of a farm decreases, initial obstacles to agtech become steeper, but this is not to say overcoming them is impossible. There have been initiatives, namely under the Green Morocco Plan, to aid small farms in gaining access to the resources and technologies previously available only to large farms.

One of the objectives of the Green Morocco Plan was to generate cooperation among farmers, focusing on smallholders. To achieve this goal, in 2018, the government began 63 aggregation projects intended to create ties among numerous farms, grouping them together to facilitate exchange of skills, knowledge, and resources, helping to lower barriers to adopting digital technologies. The projects involved 55,000 farmers, 80% of whom worked at small farms. Small farms, however, typically do not have the resources and time to participate in these projects, many of which focus on sufficient yield for exports and attracting large investments (European Training Foundation, 2021). Additionally, 20B Moroccan dirham was invested in 55 "social projects," with the purpose of benefiting 855,000 people, specifically vulnerable smallholding farmers. These projects are focused on disadvantaged areas and work on conserving natural resources. One major project category was cooperative aggregation (Agency for Agricultural Development, 2015).

Various agricultural cooperatives as well as institutions and agencies are pushing to make agtech accessible to small farmers in Morocco. The National Office of Agricultural Consulting specifically is working directly with farmers to disseminate the technologies that the National Institute of Agricultural Research is investigating (European Training Foundation, 2021). These efforts are a way of investing in the technological development of Morocco's agricultural sector broadly, specifically in support of smallholders.

Paths to implementation

There already are some financial investments and policy changes paving the way to digital transition. However, to react at the same onset rate as climate change impacts, stronger action must be taken. Morocco is investing funds in digital technology in part to address the impact of climate change on agriculture. The government recently approved a framework agreement allocating $991M to mitigate the stress that decreased rainfall and global economic issues place on the agriculture sector. A major objective of this allocation is to assist farmers struggling with these recent challenges while reducing the costs of agricultural production (Sahnouni, 2023). The Agency for Agricultural Development also has access to the Adaptation Fund and Green Climate Funds to support efforts to combat climate change (Ministry of Agriculture…, n.d.-b). Digital technology falls under these allocations. The Generation Green plan is also investing in digital technology (discussed previously). As part of Generation Green, R&D investments for agricultural technology will be multiplied up to 2 times (Ministry of Agriculture…, n.d.-d). Generation Green is laying a framework of mechanisms to connect more than two million Moroccan farmers to digital service platforms and is hiring 5000 private agricultural advisors who can support farmers around the country (Ministry of Agriculture…, n.d.-c). With these specific government actions, digital technologies will be accessible to farmers and more widespread in Morocco.

Educational institutions in Morocco also play a large role in bringing digital technologies to farmers, often in form of agricultural consulting. The National Office of Agricultural Consulting facilitates assisting farmers with innovative farming strategies, often using new technologies (Agency for Agricultural Development, 2015). Educational institutions themselves play a significant role in R&D of technologies and their applications and dissemination.

Morocco's government is also playing a role in coordinating global partners to further digitalize the agricultural sector (Jabir & Falih, 2020). The World Bank, for example, has invested in the Morocco Digital and Climate Smart Agriculture Program, which promotes the use of digital and climate smart technologies throughout the supply chain of Morocco's agricultural sector. The total cost of the program is $1B (World Bank, 2019). Additionally, the World Bank provided two loans to Morocco, $205M in 2011 and $203M in 2013, to support the Green Morocco Plan and financed efforts through the National Irrigation Water Saving Program (World Bank, 2017). In 2021, Morocco received $1.63M from the UN International Fund for Agricultural Development and has since seen a similar yearly contribution (Trading Economics, 2024a). One additional nation-specific effort has been the German-Moroccan Excellence Center for Agriculture, established in 2013 as a place where farmers and extension staff can access information on modern agricultural technologies (Qamar, 2013). International financing agencies like

the World Bank are interested in investing in digital technology in Moroccan agriculture: because Morocco is setting itself up as a digital hub and with its agricultural sector hit so heavily by climate change, a perfect storm has been created for an agtech revolution.

Challenges

There are several challenges preventing a seamless transition to digital agriculture. Engineers, specifically sensor engineers, are needed for setting up and providing maintenance for digital technologies, skill sets not present in traditional agriculture. Additionally, engineers often hold graduate degrees, thus generally demanding higher wages. The agricultural sector, especially when considering smaller and remote farming regions, cannot necessarily afford to hire these engineers. There is also a lack of qualified engineers to fill those positions, with 25% of engineering graduates in Morocco going abroad for work (European Training Foundation, 2021).

Another challenge for the digital transformation of Moroccan agriculture stems from limits on agricultural education and training, a result of lack of funding and ceilings on the number of farmers who can be assisted. The Hassan II Agronomic and Veterinary Institute can take in a limited number of engineering students each year and in fact had to cancel its vocational education and training track due to a lack of resources and teachers (European Training Foundation, 2021). Typically, educational institutions' limited capacities have their greatest impact on vocational education and training programs, which are necessary to train farmers in using new technologies; this limitation is hindering agtech development.

Adherence to tradition is another roadblock in moving to digital agriculture. It is natural to want to continue operating as in the past, especially when it comes to something as personal as one's livelihood. When transitioning to digital technologies, emphasizing their economic benefits (higher yield and lower input and maintenance costs) can help convince farmers that the initial investment in agtech may be worthwhile. Small farmers tend to be focused on short-term goals, for instance, meeting production requirements each season, and may not want to implement newer technologies, as they are not often interested in larger markets. For this reason, even if there are subsidies to aid in the initial costs, smaller farmers may not want to change their methods (European Training Foundation, 2021). Ways to offset these roadblocks need to be implanted to ensure a successful agtech transition.

Recommendations

The path to implementation of agtech should rely heavily on education for farmers, particularly those in remote areas. To do this, aggregation has to be incentivized and encouraged to bring small farms together and find easier ways to relay information and resources to them. Additionally, specific efforts by the government can lower barriers (primarily cost) to agtech's implementation. The government must also expand investment in R&D and in extension agencies to ensure effectiveness.

There is already a trend toward aggregation in Morocco, and this should continue; it is realistically the only way small farms will be able to overcome their barriers and gain access to digital technologies. One example of government assistance for aggregation is establishing cooperatives (including for farmers), through the Office of Cooperation Development, under the Ministry of Tourism, Handicrafts, and Social and Solidarity Economy. Cooperatives help ensure that farmers can readily access the support and technological services of extension agencies (Qamar, 2013). Additionally, having larger farms belonging to aggregations along with smaller farms can aid in transferring technologies and information, with resources of the large farms helping to overcome initial barriers for the small ones. Aggregation will allow for not only the exchange of information but also the creation of a group that has sufficient purchasing power to acquire the agtech that small farms may not have on their own.

The Moroccan government can play a significant role in how quickly and to what extent the agricultural sector makes a digital transformation. By subsidizing agtech, the government can lower the cost barrier, allowing digital technologies to become more common on farms, thus boosting agricultural production and thereby benefiting the economy overall.

R&D investments, traditionally underfunded, must be expanded to allow for a full digital transformation of Moroccan agriculture. Investments can be sourced governmentally, privately, internationally, or, ideally, through a combination of all three. The technologies themselves can be further researched to be more effective and affordable. Additionally, investment can take the form of improving dissemination strategies. In combination, this will make digital technology more accessible in Morocco, especially for smaller and remote farms.

With access to agtech, Morocco can improve working conditions for farmers. Tasks such as data collection and pesticide, herbicide, and fertilizer

application can be carried out with these technologies, saving farmers time and manual labor. Additionally, digital technologies, although sometimes having high initial costs, save farmers money in the long run, with higher precision and less fertilizer, pesticide, herbicide, and water usage. Digital technologies' accuracy in predictions of weather and determination of crop needs leads to better yield, consequently increasing profit for farmers and lowering the risk of financial loss from failed crops. Digital technologies can combat the impacts of climate change and lessen agriculture's contribution to it by reducing chemical and water waste. Agtech lends agriculture a dynamic quality that Morocco can use to preserve the strength of this crucial industry in the face of climate change challenges.

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