EMERGING TRENDS IN AGRICULTURAL TECHNOLOGY FOR EFFICACY IN MODEL FARMING AND SUSTAINABLE FOOD PRODUCTION

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Abstract

The general global community has been plagued by peculiar traumas, consequent upon the effect of climate change; connected to environmental, societal and economic dilemmas. Subsequently, the outbreak of pandemics and wars among others have truncated the pathway to conventional agrarian system, upon which majority of our larger society have lived on. These global challenges pose threats to food security and safety. The challenges call for urgent need for innovation, scientific responses and technological approaches. Backed by the many current alarming situations, many food-related trends have emerged in recent times in quick response to the global issues. This work therefore, is directed at unveiling possible technologies in the agricultural and food industry that could replace the conventional, exhaustive and less-proficient methods, to a shift to approaches that are more result-oriented agricultural productivity and food sustainability. The quantity in terms of yield and food quality is also is highly sustained. The trends include, but not limited to food production system, such as: indoor vertical farming, farm automation, livestock farming, sensor and data technology, greenhouse, precision agriculture, artificial intelligence, crop monitoring, livestock, monitoring, farming drones, and autonomous farming machines. The benefits of the modern trends to food production and security are in-exhaustive; nevertheless, this has however not exonerated the innovation from myriads of its peculiar challenges, while pursuing the most appropriate and rewardable methods

Key Words: Agricultural Technology, Emerging Trend, Food Production, Food Sustainability, Sustainable Farming

Introduction

Demand for food is growing at the same time the supply side faces constraints in land and farming inputs. However, the agricultural industry is confronted by two significant obstacles (adopting new trend and yield output). Agriculture, one of the world's oldest industries, finds itself at a technological crossroads. To handle increasing demand and several disruptive trends successfully, the industry will need to overcome the challenges to deploying advanced connectivity. This will require significant investment in infrastructure and a realignment of traditional roles. It is a huge but critical undertaking (Rinkesh, 2023).

In the very recent times, several factors are facilitating the adoption of technologies for sustainable farming systems. Research and development efforts, the trend towards better education and training of farmers, the shift in the focus of advice, quicker and cheaper means of disseminating and sharing information, availability of financial resources, pressures from consumers, non-government organizations, the media and the public in general are contributing towards facilitating the adoption of sustainable farm technologies (Vernon, 2008; Mohd, 2022). Many policies, including those relating to agriculture, environment, and research and development, are providing a combination of incentives and disincentives to technology adoption. Environmental policies themselves increasingly constrain farmers' actions, as do zoning regulations, animal welfare standards and public health policies (Goedde & Katz, 2020).

INN (2020),opined that, to address these forces poised to further reimburse the industry, agriculture must embrace an adoptable technology from the local rural levels to a more industrialized sector. According to Kurukulasuriya (2013), past advances were mostly mechanical, in the form of more powerful and efficient machinery, and genetic, in the form of more productive seed and fertilizers. Now much more sophisticated, digital tools are needed to deliver the next productivity leap. Some already exist to help farmers more efficiently and sustainably use resources, while more advanced ones are in development. These new technologies can upgrade decision making, allowing better risk and variability management to optimize yields and improve economics (Botta, 2022). Technologies are increasingly being developed in a global market, applied at the farm level but impacting on sustainability beyond the farm. Both conventional and newer technologies, in particular related to biotechnology, information and precision farming techniques, are global businesses. The dissemination of those technologies is often within the national market, but their application is local (Bhutani, 2019; Geosci, 2022). However, the effects on sustainability of farm level adoption extend beyond the farm. With more vertical integration, either through formal ownership structures or contractual relations along the whole food chain, decisions on the adoption of technologies at the farm level often cannot be separated from decisions taken elsewhere in the food chain (Vernon, 2008).

Adopting technologies for sustainable farming systems involve uncertainty and trade-offs. Technologies that can contribute to an economically efficient farm sector and the financial viability for farmers, while improving environmental performance and which are socially acceptable will provide "triple dividends" to sustainability. Given the scarcity of resources, however, there are invariably trade-offs in achieving these sustainability goals (INN, 2020; Rinkesh, 2023). Moreover, the aims are "moving targets" which must address new issues and changing priorities. Technological developments are rapidly evolving and information on the costs and benefits of adopting technologies in agriculture is often imperfect. Thus, the choices on technology adoption are made in a climate of uncertainty with a large element of "trial and error" in its application, and the speed and extent of adoption varies considerably among farmers. This can have important implications as to the structure of farms and the number of farmers that are able to survive financially in the future (Tilman et al., 2011).

Concept of Agriculture and need for Technology Development

Agriculture remains the fulcrum of the Nigerian economy; despite the presence of oil in the country. It is the main source of livelihood for most Nigerians (Food and Agriculture Organization of the United Nations (FAO, 2020). Agriculture today, is about so much more than

a farmer simply planting crops, rearing animals or domestication of aquatic organisms. It takes a whole ecosystem and a host of actors to work together to produce the food we need for a population of more than seven billion people. (Geosci, 2022)

Agricultural technology is the use of technology in agriculture, horticulture, and aquaculture with the aim of improving yield, efficiency, and profitability. Agricultural technology can be products, services or applications derived from agriculture that improve various input/output processes (NIFA, 2020; Sergieieva, 2023). This complex agricultural production system has evolved over time through scientific discoveries and other innovations. It is this dynamic nature that will equip agriculture to cope with the competing challenges of addressing food and nutrition security, improving livelihoods, combating climate change and sustainably managing natural resources Modern innovative technologies, processes, products and services would be disseminated, adapted and put to better use, to make these farmers more productive and competitive and improve their standards of living in a framework of sustainable and efficient use of natural resources (Campbell, 2002). According to NIFA (2020) and Encyclopedia (2020), technological innovations have greatly shaped agriculture throughout time. From the creation of the plow to the Global Positioning System (GPS) driven precision farming equipment, humans have developed new ways to make farming more efficient and grow more food. We are constantly working to find new ways to irrigate crops or breed more disease resistant varieties.

Technological change has been the major driving force for increasing agricultural productivity and promoting agriculture development across the globe. In the past, the choice of technologies and their adoption was to increase production, productivity and farm incomes. Over many decades, policies for agriculture, trade, research and development, education, training and advice have been strong influences on the choice of technology, the level of agricultural production and farm practices (Campbell, 2002; Tilman et al., 2011)

Agriculture is becoming more integrated in the agro-food chain and the global market, while environmental, food safety and quality, and animal welfare regulations are also increasingly impacting on the sector (Agricultural Technology Centre [ATC], 2020). It is faced with new challenges to meet growing demands for food, to be internationally competitive and to produce agricultural products of high quality. At the same time, it must meet sustainability goals in the context of on-going agricultural policy reform, further trade liberalization and the implementation of multilateral environmental agreement (Kurukulasuriya, 2013).

Today, farmers, advisors and policy makers are faced with complex choices. They are faced with a wide range of technologies that are either available or under development; they must deal with the uncertainties of both the effects these new technologies will have throughout the agri-food chain and the impact that a whole range of policies will have on the sustainability of farming systems (United Nations Environment Programme [UNEP], 2011; Olayide et al., 2016).

Assessment of Technology for Sustainable Farming

Assessing technologies for farming systems from a sustainability perspective is in its infancy; especially in developing countries with the likes of Nigeria (IAASTD, 2009). The level of readiness to adopt modern technology is worrisome on the other hand the geographical disparity in locations and climate calls for pro-activeness in finding lasting solution to the challenge (Botta, 2022). Assessing the role of technology in sustainable farming, Goedde & Katz (2020) opined that, until recently, the impacts of farm technologies were assessed according to relatively few, generally clear and measurable criteria:

- production,
- productivity,
- farm incomes,
- employment, and
- trade.

Assessing sustainability is more complex when environmental, social and ethical considerations must be taken into account. It is often not clear what the relationships are between the various elements of sustainability, what should and can be measured, and how the results are to be interpreted so that farmers, policy-makers and other stakeholders can identify with reasonable confidence which sustainable technologies work, which channels can best facilitate their dissemination and adoption in different conditions, and at what cost and benefit (World Bank, 2007; Bhutani, 2019).

Operational trends in Modern Technology for Sustainable Farming

There are a number of emerging technologies in farming which promote agricultural activities among the youth, ageing and the farming environment. They "ease" production, increase the efficiency and utilization of equipment, increase production as well as distribution and preservation of farm products. Goedde & Katz (2020); Botta, (2022); Mohd, (2022) and Rinkesh (2023) described new and adoptable technology in contemporary agriculture as:

Indoor Vertical Farming

Indoor vertical farming can increase crop yields, overcome limited land area, and even reduce farming's impact on the environment by cutting down distance traveled in the supply chain. Indoor vertical farming can be defined as the practice of growing produce stacked one above another in a closed and controlled environment. By using growing shelves mounted vertically, it significantly reduces the amount of land space needed to grow plants compared to traditional farming methods. This type of growing is often associated with city and urban farming because of its ability to thrive in limited space. Vertical farms are unique in that some setups do not require soil for plants to grow. Most are either hydroponic, where vegetables are grown in a nutrient-dense bowl of water, or aeroponics, where the plant roots are systematically sprayed with water and nutrients. In lieu of natural sunlight, artificial grow lights are used.

Vertical farms use up to 70% less water than traditional farms. From sustainable urban growth to maximizing crop yield with reduced labor costs, the advantages of indoor vertical farming are apparent. Vertical farming can control variables such as light, humidity, and water to precisely measure year-round, increasing food production with reliable harvests. The reduced water and energy usage optimizes energy conservation -- vertical farms use up to 70% less water than traditional farms. Labour is also greatly reduced by using robots to handle harvesting, planting, and logistics, solving the challenge farms face from the current labour shortage in the agriculture industry.

Farm Automation

Farm automation often associated with "smart farming", is technology that makes farms more efficient and automates the crop or livestock production cycle. Although these technologies are fairly new, the industry has seen an increasing number of traditional agriculture companies adopt farm automation into their processes. New advancements in technologies ranging from robotics

and drones to computer vision software have completely transformed modern agriculture. The primary goal of farm automation technology is to cover easier, mundane tasks. Some major technologies that are most commonly being utilized by farms include: harvest automation, autonomous tractors, seeding and weeding, and drones. Farm automation technology addresses major issues like a rising global population, farm labour shortages, and changing consumer preferences. The benefits of automating traditional farming processes are monumental by tackling issues from consumer preferences, labour shortages, and the environmental footprint of farming.

Livestock Farming, Sensor and Data Technologies

The traditional livestock industry is a sector that is widely overlooked and under-serviced, although it is arguably the most vital. Livestock provides much needed renewable, natural resources that we rely on every day. This technology can come in the form of nutritional technologies, genetics, digital technology, and more. Livestock technology can enhance or improve the productivity capacity, welfare, or management of animals and livestock. This technology has huge benefits for the current livestock industry. It can improve the productivity and welfare of livestock by detecting sick animals and intelligently recognizing room for improvement.

Greenhouses

In recent decades, the Greenhouse industry has been transforming from small scale facilities used primarily for research and aesthetic purposes (i.e., botanic gardens) to significantly more large-scale facilities that compete directly with land-based conventional food production. Nowadays, in large part due to the tremendous recent improvements in growing technology, the industry is witnessing a blossoming like no time before. Greenhouses today are increasingly emerging that are large-scale, capital-infused, and urban-centered. Modern greenhouses are becoming increasingly tech-heavy, using LED lights and automated control systems to perfectly tailor the growing environment.

Precision Agriculture

Agriculture is undergoing an evolution - technology is becoming an indispensable part of every commercial farm. New precision agriculture companies are developing technologies that allow farmers to maximize yields by controlling every variable of crop farming such as moisture levels, pest stress, soil conditions, and micro-climates. By providing more accurate techniques for planting and growing crops, precision agriculture enables farmers to increase efficiency and manage costs. Precision agriculture companies have found a huge opportunity to grow.

Artificial Intelligence

The rise of digital agriculture and its related technologies has opened a wealth of new data opportunities. Remote sensors, satellites, and unnamed Aerial Vehicles (UAVs) can gather information 24 hours per day over an entire field. These can monitor plant health, soil condition, temperature, humidity, among others. The idea is to allow farmers to gain a better understanding of the situation on ground through advanced technology (such as remote sensing) that can tell them more about their situation that they can see with the naked eyes. The aim is that farmers can use this artificial intelligence to achieve their goal of a better harvest through making better decision in the field.

Crop Monitoring

Connectivity offers a variety of ways to improve the observation and care of crops. Integrating weather data, irrigation, nutrient, and other systems could improve resource use and boost yields by more accurately identifying and predicting deficiencies. For instance, sensors deployed to monitor soil conditions could communicate via LPWAN, directing sprinklers to adjust water and nutrient application. Sensors could also deliver imagery from remote corners of fields to assist farmers in making more informed and timely decisions and getting early warnings of problems like disease or pests.

Livestock Monitoring

Preventing disease outbreaks and spotting animals in distress are critical in large-scale livestock management, where most animals are raised in close quarters on a regimen that ensures they move easily through a highly automated processing system. Chips and body sensors that measure temperature, pulse, and blood pressure, among other indicators, could detect illnesses early, preventing herd infection and improving food quality. Farmers are already using ear-tag technology from providers such as Smart bow (part of Zoetis) to monitor cows' heat, health, and location, or technology from companies such as All flex to implement comprehensive electronic tracing in case of disease outbreaks. Similarly, environmental sensors could trigger automatic adjustments in ventilation or heating in barns, lessening distress and improving living conditions that increasingly concern consumers.

Building and Equipment Management

Chips and sensors to monitor and measure levels of silos and warehouses could trigger automated reordering, reducing inventory costs for farmers, many of whom are already using such systems from companies like Blue Level Technologies. Similar tools could also improve shelf life of inputs and reduce post-harvest losses by monitoring and automatically optimizing storage conditions. Monitoring conditions and usage of buildings and equipment also has the potential to reduce energy consumption. Computer vision and sensors attached to equipment and connected to predictive-maintenance systems could decrease repair costs and extend machinery and equipment life.

Farming by Drone

Agriculture has been using drones for some two decades, with farmers around the world relying on pioneers like Yamaha's RMAX remote-controlled helicopter to help with crop spraying. Now the next generation of drones is starting to impact the sector, with the ability to survey crops and herds over vast areas quickly and efficiently or as a relay system for ferrying real-time data to other connected equipment and installations. Drones also could use computer vision to analyze field conditions and deliver precise interventions like fertilizers, nutrients, and pesticides where crops most need them. Or they could plant seed in remote locations, lowering equipment and workforce costs. By reducing costs and improving yields, the use of drones could generate enormous income value.

Autonomous Farming Machinery

More precise GPS controls paired with computer vision and sensors could advance the deployment of smart and autonomous farm machinery. Farmers could operate a variety of equipment on their field simultaneously and without human intervention, freeing up time and

other resources. Autonomous machines are also more efficient and precise at working a field than human-operated ones, which could generate fuel savings and higher yields. Increasing the autonomy of machinery through better connectivity could create huge level of profit to the farmer.

Benefits of agriculture technology in promoting sustainable farming

The implementation of smart agricultural technology is advantageous for all players in the agri-food chain. With its use in optimizing and automating agricultural operations and field activities, growers and landowners can now save significant amounts of time and effort. Sergieieva (2023); Goedde & Katz (2020) identified examples of how farming has benefited from advances in agriculture technology as follows:

- using less water, fertilizer, pesticides, and other inputs allows agricultural producers to cut costs and keep more of their profits;
- by preventing or drastically reducing the amount of chemical runoff into waterways, businesses lessen agriculture's impact on the environment and take steps toward greater sustainability;
- increasing crop yield, while decreasing labor inputs;
- making it easier for farmers, agronomists, or other agricultural workers to communicate and coordinate activities using mobile devices, apps, or web-based resources;
- lowering barriers to accessing agricultural insurance and financial services as well as market and technological data;
- mitigation of the damage that could be caused by pests, natural calamities, and weather in agriculture with the help of affordable, always-on agricultural monitoring systems;
- increase in farm income through improved product quality and increased quality controls;
- timely recognizing nutrient deficiency in plants and notifying agricultural producers of the type and amount of fertilizer and other amendments needed;
- ability to foresee potential problems on the farm through the visualization of production patterns and trends gleaned from an analysis of current and historical agricultural data. By estimating their overall crop yield, agricultural producers can precisely budget for the next growing season and better prepare for emergencies.

Barriers associated with Adoption and Implementation of Technology by Farmers

Bhutani (2019) highlighted some factors hindering the adoption of appropriate technologies for sustainable farming systems as follows:

- economic profitability of the technology;
- farmer's financial constraints and access to credit;
- farmer's familiarity with the technology, and his knowledge and education levels;
- conservative attitudes of farmers and local authorities (which can make them slow to adopt)
- structural factors such as size of the farm for example, precision farming is good for large farms, but expensive for small farms.
- cost of new technology to farmer new technologies are often expensive when they are first introduced, thus penalizing early adopters;

- scale of production for the technology technologies produced in small quantities have difficulties to get market access.
- Some agricultural policies impose environmental constraints on farmers as a condition for receiving support, but at levels higher than otherwise to compensate for environmental damage caused by other agricultural policies.

Conclusion

The modern agricultural business is evolving in a variety of directions at the same time. However, its primary focus is utilizing agricultural technologies to boost crop yields through better planning and smarter management. By promoting more efficient and sustainable farming methods, advanced technology in agriculture helps farmers prosper in today's agribusiness. Time-tested practices like crop rotation and new agricultural technologies, such as monitoring field productivity with machinery and satellite images or special farming software, all contribute to the viability of agriculture. Agricultural technology aims to make work in the field more efficient and convenient. Each year, there are various new agricultural innovations and, occasionally, ground-breaking technologies. As agribusiness continues to modernize and grow, it is becoming increasingly crucial for agricultural consultants, food producers, and technology managers to be knowledgeable and up-to-date with the latest technological standards.

Recommendations

1. There is a need for greater follow-up in tracking the adoption of technologies for sustainable farming systems and in the accountability of research efforts and policies for technology dissemination and adoption
2. Rigorous ex-post assessments of results could help ensure that corrections are made before too much is invested in the wrong technology.
3. This is important as technologies affecting agriculture arise from a wide range of sources; ranking technologies and identifying possible future trends can help the policy making process in moving towards sustainable agriculture.
4. The adoption of technologies for sustainable farming systems will be facilitated by a wider participatory approach involving a range of stakeholders. These stakeholders should include farmers, the agri-food industry, consumer groups and non-government organizations with an interest in sustainable farming.
5. Sustainable technologies are implemented at the farm level; thus, a key requirement is to engage farmers in the dialogue on technology adoption. Ideally, there should be a greater sense of "ownership" throughout the agri-food chain in the choice of technology.

6. The governments should influence the adoption of farming practices and technologies through policies implementation, support research and demonstration farms that can contribute towards the adoption of technologies.

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