Precision Farming, Soil Conservation, and Irrigation as Veritable Impetus for Boosting Agricultural Productivity

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ABSTRACT

Numerous regions depend on agriculture for their livelihoods. It is widely known that agricultural productivity is important to the overall economy. It is a key driver for the well-being of farmers, the agro-based industry, and the general economy. The term "soil conservation is the prevention of soil loss from erosion or reduced fertility caused by over usage, acidification, salinization, or other chemical soil contamination, so as maintain soil fertility and productivity", while the term" irrigation" is the artificial application of water to overcome deficiencies in rainfall for growing crops. Irrigation is a basic determinant of agriculture because its inadequacies are the most powerful constraints on the increase of agricultural production. The term "Precision Agriculture" (PA) is used as a farming management concept based on observing, measuring, and responding to inter- and intra-field variability in crops.

This study highlighted the factors affecting agricultural productivity. The various ways in which soil conservation enhances agricultural productivity as well as the methods and techniques of soil conservation were discussed, while the concept of irrigation and roles in boosting agricultural productivity was enumerated. This paper seeks to illuminate the concept of precision farming, merits, importance, and challenges. Investment in developing new farming techniques and in researching new approaches to farming need to be continued on a daily basis.

(Keywords: agricultural productivity, irrigation, precision farming, sensors, soil conservation)

INTRODUCTION

Agriculture constitutes only about one-fifth of Africa's GDP and about half of the total value of its exports, about 75% of the world's poor people live in rural areas and 86% of them work in agricultural sector for their livelihood [1]. The growth of the yield of major food crops, especially grains, throughout the world is about 1% per year [2], whereas the recent world population growth rate is about 1.2%.

It is widely known that agricultural productivity is important to the overall economy. It is a key driver for the well-being of farmers, agro-based industry, and the general economy. It is linked to food security, food prices, and poverty alleviation in the developing countries [3]. In addition, food supplies have to be geared towards meeting the challenges of increasing global population, changes in income, and the resultant changes in diet [4]. Hence, research on agricultural productivity is of paramount importance.

There are indices indicating increases in agricultural productivity which includes reduce poverty, real income changes, employment generation, non-farm livelihood assets, access to education, and overall health [3]. Agricultural production takes place in an environment characterized by risk and uncertainty [3]. This is particularly so in arid and semi-arid zones where water supply to crops from rainfall is variable and erratic. Even in areas under irrigation, water scarcity is not uncommon, and yields are often affected, therefore procedures and tools are needed to apply precise and correct amount of inputs like water, fertilizer, pesticides, and other inputs at the correct time to the crop to reduce uncertainty and to manage risk in order for increasing its productivity and maximizing its yields.

Low agricultural productivity has been attributed to the low use of fertilizer, the loss of soil fertility, and traditional, low technology, rain-fed farming systems [3]. A number of different factors can cause agricultural productivity to increase or decrease. It is important to note that productivity is not an absolute measure, but rather a reflection of the ratio between inputs and outputs. Factors affecting agricultural productivity are as highlighted by [3] are as follows:

Weather: unusual weather patterns, such as drought, a prolonged rainy season, early or late frosts and other factors can ruin crops and bring productivity down.

The Capacity of a Given Farm: soil can't be forced to produce beyond capacity, although there are methods that can be used to improve production capacity, such as proper fertilizing to add nutrients to the soil so that it can support more crops.

Pests: infestations occur or not according to certain weather conditions - in addition to spoiling crops, pests can add significantly to the costs of producing a crop. Controlling them may require measures such as fencing, chemical or biological treatments, companion planting or crop rotation, all of which change the ratio of inputs to outputs

Available Equipment: in regions where access to mechanized farm equipment is low, agricultural productivity can also be low as people handle their crops primarily by hand. This involves a big investment of time, energy and money and also limits the total capacity of the land.

Supply and Demand in the Market: farmers will adjust their activities to meet the needs of consumers, and this can have an impact on agricultural productivity. In some cases, governments even pay subsidies to farmers to compensate them for not growing crops, which can skew productivity measures.

In order to boost agricultural productivity, the following agricultural productivity innovation key factors must be adopted such as soil conservation, irrigation and precision farming.

SOIL CONSERVATION

Soil conservation: is a combination of practices used to protect the soil from degradation. It involves treating the soil as a living ecosystem and recognizing that all the organisms that make the soil their home, play important roles in producing a fertile healthy environment. Soil conservation enhances agricultural productivity and methods and techniques for soil conservation were highlighted many researchers such as [5 – 9].

Soil Conservation enhances agricultural productivity as follows:

(a) **To maintain an adequate amount of organic matter and biological life in the soil.** These two components promote soil productivity which enhances crop yield

(b) **To ensure a secure food supply at reasonable prices.** Soil conservation is proven to increase the quality and quantity of crop yields over the long term because it keeps topsoil in its place and preserves the high long-term productivity of the soil.

(c) **To save farmers money.** It prevents erosion that contributed to lost income due to lower crop yields, and the loss of nutrients from the soil.

(d) **To improve water quality.** All forms of life need clean water to survive. Agricultural and urban soil erosion is major sources of sedimentation and contamination of water supplies.

(e) **To improve wildlife habitat:** It provides buffer strips and windbreaks, or replacing soil organic matter, greatly enhance the quality of the environment for wildlife of all kinds.

(f) **For aesthetic reasons:** To provide more attractive and picturesque scenery.

(g) **To help create an environment free of pollution where we can live safely.**

(h) **For the future of our children, so that they may have enough soil to support life.** It has been said that the land has not so much been given to us by our forefathers but has been borrowed from our children.

Methods and Techniques of Soil Conservation: Many different techniques have been invented throughout the years with the aim of preserving the nutrient level of the soil, preventing erosion and enhancing agricultural productivity.

Keyline Design: It refers to topographic feature linked to water flow and a version of contour plowing. It allows the water runoff to run directly into an existing water channel and prevent soil erosion caused by the water.

- **(a) Terrace Farming**: Terracing is a method of carving multiple, flat leveled areas into hills. Steps are formed by the terraces which are surrounded by a mud wall to prevent run off and hold the soil nutrients in the beds. More commonly found in lesser developed nations due to the difficulty of using mechanized farming equipment in the terraces.

- **(b) Contour Plowing**: It involves plowing grooves into the desired farmland, then planting the crop furrows in the grooves and following the contours. It a very effective way for farmland on slopes to prevent runs off improves crop yields.

- **(c) Perimeter Runoff Control**: This is the practice of planting trees, shrubs and ground cover around the perimeter of your farmland which impedes surface flows and keeps nutrients in the farmed soil.

- **(d) Windbreaks**: Planting of rows of tall trees in dense patterns around the farmland and prevents wind erosion.

- **(e) Cover Crops/Crop Rotation:** Cover crops such as legumes and radishes are rotated with cash crops in order to blanket the soil all year- round and produces green manure the replenishes nitrogen and other critical nutrients. Using cover crops can also suppress weeds.

- **(f) Soil Conservation Farming**: A mixture of farming methods intending the mimic the biology of virgin land. These practices can be used to prevent erosion and even restore damaged soil and encourage plant growth. Eliminating the use of nitrogen fertilizer and fungicides can increase yields and protect crops from drought and flooding.

- **(g) Agrostological Measures**: Planting grass in heavily eroded areas is called an agrostological measure. Ley farming practices cultivating grass in rotation with regular crops to increase the nutrient level in the soils. When the grass is harvested it can be used as fodder for cattle.

- **(h) No till farming**: This is the method of growing crops year-round without changing the topography of the soil by tilling or contouring. This technique increases the amount of water that penetrates the soil and can increase organic matter of the soil which leads to larger yields.

- **(i) Green Manures**: Green manures are a few different crops that can be grown, not for produce or food usage, but grown in order to fertilize the farmland on which it grows. This method can improve the soil structure and suppresses the growth of weeds.

- **(j) Salinity Management**: When water evaporates from the soil, it leaves behind its salt. This can lead to damage of the soil and nutrient loss. Using humic acids can prevent this or growing crops like saltbush can rejuvenate the soils and replace lost nutrients. High levels of salt in the soil can often be caused by changes made to the water table by damming and other causes.

- **(k) Stream Bank Protection**: During floods, stream banks can often cave by constructing walls along the banks or plant useful tree species will prevent this in the future and prevent soil loss down the stream.

- **(l) Earthworms**: Earthworm casts contain a vast amount more nutrients than any natural soil in the world, and for that reason should be invited into the soils of farmland to help prevent erosion and will lead to larger crop yields.

- **(m) Mineralization**: Crushed rock or chemical supplements are added to the farmland, this helps combat mineral depletion. Normally used after flooding, it brings substantial amounts of sediment which can damage the nutrient level of the soil.

(n) Korean Natural Farming: This method takes advantage of natural and indigenous microorganisms to produce fertile soils that yield high output and gets rid of the need to use herbicides or pesticides. An improvement in soil health and output is what keeps this method used in the respective areas.

(o) Reduction of Impervious Surfaces: Driveways, patios, and paved pathways allow precipitation to flow freely off them. As the water flows it picks up momentum and in turn erodes any soil in which it flows over after leaving the impervious surfaces, reducing the amount of these around your farmland will prevent erosion.

(p) Dry Farming: In areas with a very low amount of rainfall, crops which require very little water should be grown; this will lead to the preservation of the natural levels of moisture and nutrients in the soil.

(q) Rain Gardens: A rain garden is a shallow depression in the land which holds and collects running water from impervious surfaces and prevents erosion while saving the nutrients that inevitably get washed away. This also gives you a good bed to grow wetland plants.

(r) Re-establish Forest Cover: A dense amount of trees in a forest leads to a vast network of deep roots that offer a long term solution to soil erosion, another benefit is the windbreak that these trees can provide.

(s) Maintaining pH levels of soil: Contamination of soils due to acid rains and other pollutants can lead to loss of soil fertility. Use a pH indicator monthly to check the levels of acids in the soil and treat the soils with eco-friendly chemicals to prevent a loss of crops and low yields.

(t) Indigenous Crops: The growth of indigenous crops is a good way to conserve soil, as the plants have a natural need for the nutrients in the soil in your area; they help to prevent soil erosion.

(u) Prevent Overgrazing: Try not to let overgrazing happen by moving herds around often. If overgrazing occurs, plant hardier and more nutritious species of forage in order to rebuild the soil. You can also harvest these crops and feed them to the grazers during the winter season.

(v) The Sharing of Knowledge: More developed countries can and should share their farming knowledge gained throughout the years with the lesser developed nations of the world. This will lead to a better quality of soil worldwide and can help to prevent famine and solves the food crisis in some areas of the world.

IRRIGATION

Agriculture production and water use are inextricably linked. Water has always been the main factor limiting crop production especially in arid and semi-arid zones where rainfall is insufficient to meet crop demand. A lot of factors increasing competition for finite water resources globally and the demand of agricultural produce steadily rising, it is imperatively necessity to improve the efficiency and productivity of water use for crop production, to ensure future food security and maintaining environmental sustainability. Drip irrigation is the latest technology of irrigation, is also known as trickle irrigation, it is an improved form of the sub-surface irrigation [8]. In this system water is supplied directly to the soil near the root of the plants through special outlet device called an emitter or dripper. Drip irrigation enhances agricultural productivity as follows:

(a) It provides an excellent control on water application.

(b) Minimized water loss by evaporator, seepage, deep percolation.

(c) The level of soil moisture deficit in the root zone can be maintained to a very low level.

(d) Application of fertilizers and plant nutrients directly to the root zone.

(e) Saving of irrigation water.

(f) It reduces soil erosion.

(g) Increase yield.

(h) In the absence of superfluous flow of irrigation water weed growth is minimum. It results in saving of farm labor charges.

PRECISION AGRICULTURE (PA)

The world is witnessing rapidly growing human population which has contributed to increased food demand for people's survival on the Earth. One of the challenges of any nation is meeting the food requirements with limited. Several technologies are being used in the agriculture area to boost agricultural productivity to cope with this challenge. Precision farming is one of emerging technologies and also known as digital farming. It is satellite farming or site-specific crop management (SSCM) and is a farming management concept which is based on observing, measuring, and responding to inter- and intra-field variability in crops [10].

It can be defined as an application of precise and correct amounts of inputs such as water, fertilizer, pesticides, and others, at the correct time to the crop for increasing its productivity and maximizing its yields [11]. It is comprised of near and remote sensing techniques using Internet of Things (IoT) sensors, which help to monitor crop states at multiple growth levels [12]. PA along with Mobile Wireless Sensor Network (WSN) is the main drivers of automation in the agriculture domain. It uses specific sensors and software to ensure that the crop receive exactly what they need to optimize productivity. It involves retrieving real data about the conditions of soil, crops and weather from the sensors deployed in the fields. An aim of precision agriculture is to create a decision support system (DSS) for whole farm management with the aim of boosting agricultural productivity while preserving resources. The merits and importance of precision agriculture were highlighted by [12 – 14]. Merits of precision farming include:

(1) It reduces the amount of nutrients and other crop inputs used while boosting yields [15].

(2) It increases productivity on their investment since is saving water, pesticide and fertilizer costs.

(3) It maintains environmental sustainability which promotes agricultural sustainability whereby enhancing agricultural productivity.

(4) It boosts competitiveness through more efficient practices by improved management of fertilizer usage and other inputs.

(5) It prevents soil degradation in following ways:

(i) It presents salt build up and leaching of nutrients which corrupt the quality of soil by creating undesirable changes in the essential soil chemical ingredients.

(ii) It prevents misuses or excess use of fertilizer and pesticide: The excessive and misuse of pesticides and chemical fertilizers contributing to the killing of soil's beneficial bacteria and other micro-organisms that help in soil building and formation.

(iii) It prevents salinization.

The importance of precision farming to farmers includes:

(1) It builds up a record of their farm.

(2) It improves decision making.

(3) It fosters greater traceability.

(4) It improves lease arrangements and relationship with landlords.

(5) It enhances the inherent quality of farm products.

(6) It provides precisely what parameters are needed for healthy crop, where these parameters are needed and in what amount required at a particular instance of time

The main driver of PA is a Mobile WSN, which is a network of multiple wireless nodes connected to monitor the physical parameters of environment such as soil properties, cropping practices, climatic conditions, moisture level, weeds, and disease [13]. WSN is comprised of a radio transceiver, a micro-controller, sensor(s), an antenna, along with other circuitry that enables it to communicate with some gateway to transmit information collected by the sensor(s).

Wireless sensor nodes are equipped with sensing unit, a processing unit, communication unit and power unit [13]. Each and every node is capable to perform data gathering, sensing, processing and communicating with other nodes. The sensing unit senses the environment, the processing unit computes the confined permutations of the sensed data, and the communication unit performs exchange of processed information among neighboring sensor nodes.

Mobile WSNs: These networks consist of a collection of sensor nodes that can be moved on their own and can be interacted with the physical environment. The mobile nodes have the ability to compute sense and communicate. The mobile wireless sensor networks are much more versatile than the static sensor networks. The advantages of MWSN over the static wireless sensor networks include better and improved coverage, better energy efficiency, superior channel capacity, and so on. The other drivers of PA include robots, drones, and satellite imagery, the internet of things (IoT) and smartphone applications [15 – 17].

Robots: Agricultural robots, also known as AgBots, already exit. We have advanced developed harvesting robots that identify ripe fruits, adjust to their shape and size, and carefully pluck them from branches.

Drones and satellite imagery: Drones take high quality images, while satellite capture the bigger picture. Light aircraft pilots with combination of aerial photography with data from satellite records to predict future yields based on the current level of field biomass.

Internet of Things (IoT): The Internet of Things is the network of physical objects outfitted with electronics that enable data collection and aggregation. It operates through the uses of sensors and farm-management software [15].

Smartphone applications: Smartphone come with many useful applications storage devices include camera, microphone, Global Positioning System (GPS) accelerometer. They are simple, portable, affordable, and have a high computing power [18]. It is useful in various agriculture applications such as field mapping, tracking animal, obtaining weather and crop information, and more.

Machine Learning: It is commonly used in conjunction with droves, robots, and internet of things devices. It allows for the input of data from of these sources which allows for more efficient and precise farming with less human manpower [17].

Some of the most common sensors used in the agriculture domain that capture environmental parameters related to crops are presented in Table 1.

Similarly, there are various communication protocols due to increase in IoT devices and WSN technologies. The most commonly used protocols for wireless communication in IoT devices and WSN technologies-based applications in agriculture are presented in Table 2.

Each protocol has its own specifications depending on the bandwidth, number of free channels, data rate, battery timing, price, power, topology, area cover and physical range. 6LoWPAN and ZigBee are considered to be more suitable for PA application because both are based on mesh networking, which makes them suitable to cover large area [19].

Table 1: Wireless Nodes used in the Agriculture Domain.

S/N	Sensor Name	Parameters Captured
1	ECH$_2$O Soil moisture sensor	Soil Temperature, Soil Moisture, Conductivity
2	Hydra probe 11 soil sensor	Soil Temperature, Salinity level, Soil Moisture, Conductivity
3	MP406 Soil moisture sensor	Soil Temperature, Soil Moisture
4	EC sensor (EC250)	Soil Temperature, Salinity level, Soil Moisture, Conductivity
5	Pogo portable soil sensor	Soil Temperature, Soil Moisture
6	107-L temperature sensor	Plant Temperature
7	237 leaf wetness sensor	Plant Moisture, Plant wetness, Plant Temperature
8	SenseH2^{TM} hydrogen sensor	Hydrogen, Plant Wetness, CO_2, Plant Temperature
9	Field scout CM1000TM	Photosynthesis
10	YSI 6025 chlorophyll sensor	Photosynthesis
11	LW100, leaf wetness sensor	Plant Moisture, Plant Wetness, Plant Temperature
12	TT4 multi-sensor thermocouple	Plant Moisture, Plant Temperature
13	TPS-2 portable photosynthesis	Photosynthesis, Plant Moisture, CO_2
14	PTM-48Aphotosynthesis monitor	Photosynthesis, Plant Moisture, Plant Wetness, CO_2, Plant Temp.
15	CI-340 hand-held photosynthesis	Photosynthesis, Plant moisture, Plant wetness, CO_2, Plant Temp.H_2, L
16	CM-100 Compact Weather sensor	Air Temperature, Air Humidity, Wind Speed, Air Pressure
17	Met Station One (MSO)	Air Temperature, Air Humidity, Wind Speed, Air Pressure

Source: [13, 19]

Table 2: Wireless communication protocols used in Precision Agriculture (PA).

Communication Protocol	Data Rate	Topology	Standard	Physical Range	Power
6LoWPAN	0.3 – 50 Kb/s	Star, Mesh	IEEE 802.15.4	2 – 15 Km	Low
ZigBee	250 Kb/s	Star, Mesh	IEEE 802.15.4	10 – 100 m	Low
Bluetooth	1 – 2 Mb/s	Star, Bus	IEEE 802.15.1	30 m	Low
RFID	50 tags/s	P2P	RFID	10 – 20 cm	Ultra-low
LoRaWaAN	27 – 50 Kb/s	P2P, Star	IEEE 802.11ah	5 – 10 Km	Very low
WI-FI	1 – 54 Mb/s	Star	IEEE 802.11	50 m	Medium

Source: [19]

Some of common applications of wireless sensor networks used in agriculture are smart irrigation, smart fertilization, smart disease detection system and smart pest control systems [19].

Smart Irrigation System: It is an artificial irrigation application that controls the quality of water. It provides precisely amount of water required at a particular instance of time, which has a great impact on crops' hearth, cost and productivity. One of the majors expect of smart irrigation system is avoid the wastage of water.

Smart Fertilization System: It is artificial application that gives optimal amounts of fertilizers needed for the growth of the plants. It provides fertilizers in a very precise amount in order to improve productivity

Smart Disease Detection System: It is artificial application that detects disease and gives early warning to the farmers.

Smart Pest Control System: It is artificial application that provides pesticide in a very precise amount in order to prevent misuses or excess

CHALLENGES OF PRECISION AGRICULTURE

PA has been proved to enhance crop yield with reduced costs and human effort, although the adoption by farmers is still very limited due to the following challenges [13, 19]:

(1) Hardware Cost: It involves high cost of installation especially drone-based systems for crops' health monitoring.

(2) Weather Variations: It is one of major challenges and it affects the accuracy of data collection. This is caused by interruption due to interference induced in between wireless nodes and atmospheric disturbance.

(3) Data Management: It generates immense amount of data, which require high resources to perform data analysis. Besides, an intruder can corrupt the readings, false readings will adversely reduce the effectiveness of the system

(4) Literacy Rate: It influences the adoption ratio especially in underdeveloped areas where the literacy rate is not high. Besides, it is not very common due to the limitations of resources and education

(5) Interoperability: It is biggest challenges PA faces, due to different digital standards. It is slowing down their growth and inhibits the gain of production efficiency through smart agriculture applications

CONCLUSION AND RECOMMENDATION

Low agricultural productivity has been attributed to the low use of fertilizer, the loss of soil fertility, and traditional, low technology, rain-fed farming systems. Soil conservation, irrigation and precision agriculture enhance agricultural productivity. PA is a modern technology using latest technology that is WSN, IoT and Machine learning to enhance agricultural productivity by optimizing the resources such as water, fertilizers, pesticides, and others. The adoption and deployment of PA is very low due to challenges such as resources and education especially in developing and underdeveloped areas. Investment in developing new farming techniques and in researching new approaches to farming need to be on a daily basis. The Government at all levels should establish irrigation scheme to assist farmers at low-rate charges. Government at all levels should train the farmers on new technologies of farming. Establishment of Soil and Water Conservation Society (SWCS) at communities' levels.

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