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Multi-site Application of Digital Protocols and Automation in the Production, Distribution, and Utilization of Organic Fertilizer in Rwanda

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Abstract

Digital Protocol System and Automation Technologies (DPSAT) were designed to remotely monitor in real time, across all levels, the Eden Organic Fertilizer (EOF) production, distribution, and utilization. It is an integrated digital monitoring system for EOF value chains with coordination across all three levels. The Production Monitoring Layer (PML) provides the real-time tracking of composting parameters, production volumes, and quality indicators at manufacturing sites. The Distribution Management Layer (DML) ensures logistics tracking, inventory management, and transaction recording from production facilities through distribution channels to farmers and the Utilization Monitoring Layer (UML) is a field-level application that tracks, assesses soil health, and evaluates agronomic outcomes. In the production of EOF in Rwanda, a functional web portal with authentication was designed to monitor all activities across multiple sites by documenting the process of raw materials handling, pond status tracking, fertilizer stock reporting, distribution, and end-user feedback (farmers) The dashboard displays live pond statuses using traffic light color-coded indicators (green, amber and red), to give updates on fertilizer data, including quantity and total number of raw materials used. The status of each pond changes automatically based on raw material inputs and the time lag. The findings indicated that, digital protocols can significantly improve traceability, reduce wastage, optimize application rates, and enhance farmer access to quality organic fertilizer inputs while supporting Rwanda's climate-smart agriculture objectives. Before the deployment of the (DPSAT), distribution tracking relied on manual invoicing and delivery notes, with no integrated system linking production facilities to end-users. With the deployment of DPSAT, confidence is built among all stakeholders from the EOF producers through the distributors to the farmers (end users).

Keywords: Automation; Digital; Fertilizer; Organic; Ponds; Protocol

Introduction

Adoption of digital signatures by managers in charge of industries involved in large-scale production is key to the company's success and efficiency in daily operations. Remotely, activities involved in the production, distribution, and utilization of products are genuinely and constantly monitored through digital platforms. In the organic fertilizers space, management must have absolute security and control over their products from input sourcing, preparation, and loading through to output (production, bagging, and storage). Also, accurate composition of ingredients in the right proportions, timely response to inadequate raw

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material supply, and monitoring of production output in Rwanda's organic fertilizer sector could be ascertained and would also build confidence in farmers [1].

Rwanda has emerged as a leader in digital transformation in Africa, with initiatives such as the Smart Rwanda Master Plan (RMP) establishing frameworks for technology integration across sectors. In agriculture, digital solutions have been deployed through platforms like the National Agricultural Export Development Board (NAEB) traceability systems and various mobile-based farmer advisory services [1]. The agricultural sector employs approximately 70% of the population and contributes significantly to the national GDP, economic development and food security [2]. As part of the Crop Intensification Program (CIP) by the Ministry of Agriculture and Animal Resources (MINAGRI) soil fertility management through increased adoption of both mineral and organic fertilizers was prioritized [2]. The organic fertilizers, including compost, animal manure, and bio-fertilizers, offer multiple benefits beyond nutrient provision, such as improving soil structure, enhancing water retention capacity, increasing microbial activity, and reducing dependence on imported chemical fertilizers [3]. However, the organic fertilizer sub-sector remains largely analog, with manual record-keeping, limited quality monitoring, and fragmented distribution tracking.

Again, while digital agriculture is evolving, research on the value chains of organic fertilizers in East African contexts remains limited. Studies from similar applications in Kenya and Tanzania demonstrate that automated monitoring can reduce composting time by 15-20% while improving quality consistency [4]. Most studies focus on mineral fertilizers or examine single components of the value chain rather than integrated multi-site systems. This research addresses these gaps by proposing a comprehensive digital framework tailored to Rwanda's organic fertilizer sector. It is therefore important to digitize and automate the production, distribution, and utilization of organic fertilizer in Rwanda to ensure the sector's efficiency.

Materials and Methods

Description of the Study Area

Rwanda is a landlocked country in East-central Africa, lying south of the Equator (Lat:1° 56' 37.34" S and Long: 29° 52' 50.08" E) with the highest height of 4,507masl and the lowest height of 950masl. The country is bounded to the north by Uganda, to the east by Tanzania, to the south by Burundi, and to the west by the Democratic Republic of the Congo (Kinshasa) and Lake Kivu. The landscape feature is reminiscent of a tropical Switzerland, and it is dominated with a rugged, mountainous chain that runs on a north-south axis and forms part of the Congo-Nile divide. The capital is Kigali, located in the center of the country[5].

The Eden Organic Fertilizer (EOF) production facilities are located at eight (8) sites: Nyarugenge, Huye, Muhanga, Rwamagana, Nyamagabe, Musanze, Rubavu, and Gicumbi (Figure 1).

Description of Eden Organic Fertilizers (EOF) Production Sites

Two of EOF production sites (Nyarugenge and Rwamagana) are shown in Figure 2. The layout of Nyarugenge shows the various parts of the production

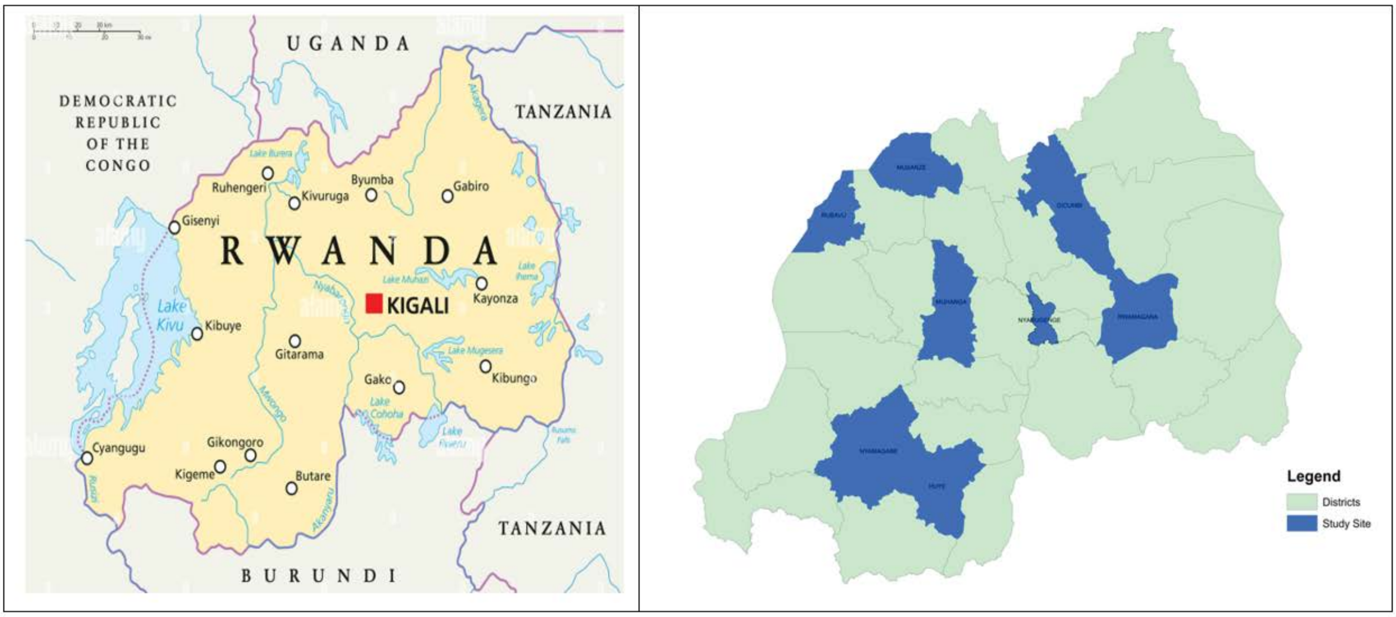

Figure 1: Map of Rwanda showing the study site [5]

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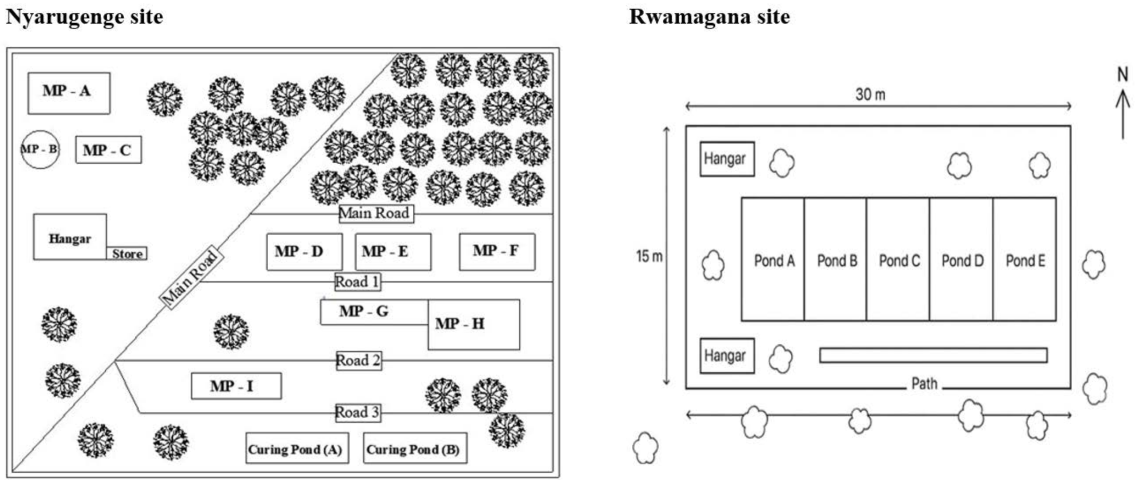

Figure 2: Layout of Nyarugenge and Rwamagana EOF production sites (source: Author,2026).

facility, with eight (8) Mixing Ponds (MP) A - I, with two (2) Curing Ponds (CP) A & B. This facility supports the flow of fertilizer material through stages of decomposition, drying, and curing. The Rwamagana EOF production facility is with the layout consisting of five (5) processing ponds (Mixing Ponds) and two (2) hangars. The ponds are aligned in a single row (Figure 2) with a spacing of 5 meters (r), and the hangars (used for storage and inspection) are located on both sides (left and right) of the ponds.

Result

Raw materials and the percentage composition of Eden Organic Fertilizer (EOF)

As shown in Table 1, six (6) types of raw materials were sourced locally, including wood (ash), human waste (biogas slurry), animal waste (cow dung, pig dung, poultry dung), and plant residues (straw). The raw materials were procured in various states that include solid, liquid, and semi-liquid, and subjected to specific pre-treatment to remove impurities such as stones, wood, polyethene bags, sacks, broken bottles, crown cook, briquettes (charcoals), etc**.** The dungs from pigs were given special treatment because of high toxicity.

Physical Composition of EOF

Two-dimensional approaches (horizontal and vertical) were used to quantify input and facilitate monitoring (Figure 3). Horizontal dimension depicts the addition of individual raw materials (biogas slurry, ash, animal dung, and plant residues. in percentages (%) into the production pond, while vertical dimension indicates the amount (quantity) of each of the raw materials added to the system in percentages (%) over time. Quantitatively, the various inputs are in the following proportions: ash (20%), biogas slurry (70%), cow dung (4%), pig dung (4%), poultry dung (1%), and the plant residues (1%). Each of the six (6) raw materials constitutes 16.7% of the total (100%). This means that the addition of two (2) raw materials, e.g., ash and biogas slurry, amounts to 33.4% horizontally, and 90% vertically, and the addition of cow dungs, poultry dungs, pig dungs, and plant residues amounts to 66.6% numerically (x-axis) and 10% quantitatively (y-axis).

Principles of Biomass and Biogas Slurry Production

Biogas Slurry is a semi-liquid mixture of decomposed organic materials, suspended in water that is obtained

Table 1: Raw materials used in the production of organic fertilizers.

S/No	Sources of Raw Materials	Raw Materials	State and Pre-treatment Methods	Impurities
1	Human waste	Biogas slurry	Liquid state, remove solid residues; screen large particles	Sand, plastics, hair, and stones
2	Animal waste (Cow)	Cow dung	Semi-solid, sun-drying, sieving	Stones and plastic bags
3	Animal waste (Birds)	Poultry dung	Dry or semi-dry, drying; grinding	Plastic bags, bottles, and rubber
4	Animal waste (Pig)	Piggery dung	Semi-solid, drying, removing non-organic waste	Stones and plastics
5	Wood	Ash	Powdery, hand and machine sorting	Stones, polythene bags, sacks, crown cork, bottles, and briquettes
6	Plant residues	Straws	Dry, chopping, grinding, and removing undecomposed materials	Stones, wood, plastics, and synthetic ropes

Source: Author,2026

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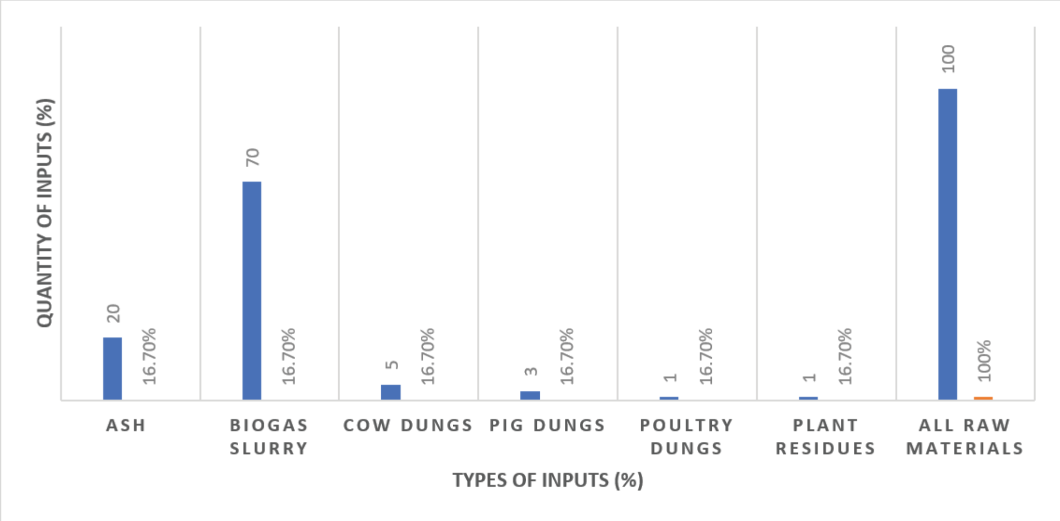

Figure 3: Percentage composition of EOF.

from animal manure, human fecal matter, food waste, and crop residues. The process begins with the collection and preparation of the organic feedstocks (raw materials). The materials are shredded or diluted with urine to achieve a manageable consistency, usually between 8–12% total solids. The biogas generated is then used as a renewable energy source for cooking & power generation.

The raw materials with specialized microorganisms inside an anaerobic digester, undergo four natural stages (hydrolysis, acidogenesis, acetogenesis and methanogenesis). Hydrolysis involves the breaking down of complex organics into simpler compounds. The conversion of these organics into volatile fatty acids and alcohols is called acidogenesis. Consequently, acetic acid and hydrogen are produced, and the process is called acetogenesis. The final stage is methanogenesis, whereby the biogas is released, leaving behind the nutrient-dense slurry (a rich, earthy-smelling digestate) packed with nitrogen, phosphorus, potassium, and beneficial microbes. The biomass/biogas slurry is then channeled into the pond for further processing into refined organic fertilizers, even though the slurry could be used directly in fields as rich organic fertilizer. In the production of EOF, the traditional nutrient content of the biogas slurry is further enhanced through the addition of farm yard manure and ash as a base.

Methods of Data Collection

The Outlook of Eden Organic Fertilizer (EOF) Production

Along the EOF production value chain, DPSAT was designed to track a total of eight (8) sites that include Nyarugenge, Huye, Muhanga, Rwamagana, Nyamagabe, Musanze, Rubavu, and Gicumbi. As shown in Table 2, data generated digitally from Rwamagana site (production), in alignment with the feedback framework on distribution and utilization showed a total of five (5) Mixing Ponds (MP) A, B, C, D and E of various dimensions (m), MP – A (Width (w)10 x Length (l) 30 x Height (h) 1.4 = 420 m^3), MP – B (14 x 32 x 1.4 = 627.2 m^3), MP – C (14 x 30 x 1.5 = 630 m^3), MP – D (14 x 30 x 1.4 = 588 m^3), and MP – E (10 x 30 x 1.4 = 420 m^3). The total volume of 2685.20 m^3 from the ponds A, B, C, D and E generated an estimated output of 42 tons, 62tons, 72 tons, 63 tons, 58.8 tons, and 42 tons, respectively, totaling an output of 267.52 tons of EOF per batch per site.

Monitoring, Distribution, and Utilization of Eden Organic Fertilizer (EOF)

As shown in Figure 4, the distribution and utilization of EOF from production and packaging, en route from the middlemen/distributors to end users (farmers and members of the cooperative societies), are monitored through the use of Internet of Things (IoT) devices, TIN, batch numbers, telephone, etc., via the Field Officer's desk to the Manager. IoT sensor networks in ex situ monitor temperature, moisture, and pH using sensors embedded in composting piles, transmitting real-time data to cloud-based platforms. Automated alerts notify the Manager when parameters deviate from optimal ranges, enabling timely interventions. Mobile applications or tablet-based systems allow facility managers to record: a) raw material inputs (type, quantity, source), b) production activities (turning schedules), c) environmental conditions, d) batch identification and tracking numbers, and e) quality test results, and transmit this data to the host system. This creates comprehensive production histories, enabling traceability and quality assurance.

The Manager escalates complaints to the Research and Development (R&D) unit of CS NJEMA for an appropriate response. The R&D unit manages the information professionally and responds by either addressing complaints in reverse order or iteratively reconfiguring the production

Table 2: EOF Production output at the Rwamagana site

Pond Characteristics		Mixing Ponds (MP)					Estimated Production
		A	B	C	D	E	
Dimension (m)	Width -W (m)	10	14	14	14	10	**62.00**
	Length -L (m)	30	32	30	30	30	**152.00**
	Height - H (m)	1.4	1.4	1.5	1.4	1.4	**7.10**
Size of Pond	W x L x H (m^3)	420	627.2	630	588	420	**2685.20**
Quantity of raw materials (% kg)	Ash (20%)	84,000	125,440	126,000	117,600	84,000	**537,040.00**
	Biogas Slurry (70%)	294,000	439,040	441,000	411,600	294,000	**1,879,640.00**
	Cow dung (4%)	16,800	25,088	25,200	23,520	16,800	**107,408.00**
	Pig dung (4%)	16,800	25,088	25,200	23,520	16,800	**107,408.00**
	Poultry dung (1%)	4,200	6,272	6,300	5,880	4,200	**26,852.00**
	Plant residues (1%)	4,200	6,272	6,300	5,880	4,200	**26,852.00**
Total Quantity of raw materials (%)		100	100	100	100	100	**500**
Total Quantity of raw materials (Kg)		420,000	627,200	630,000	588,000	420.000	**2,685,200.00**
Quantity of output (Tons)		42	62.72	63	58.8	42	**267.52.00**
No of Bags of Fertilizer (50kg)		8,400	12,540	12,600	11,760	8,400	**53,704.00**

process to address end users' requests. These cycles of interconnected web-like processes summarize the elements of the digitization process (DPSAT) in the space of distribution and utilization of EOF.

The Design of Automated Model Organic Fertilizer Production Mixing Ponds.

At each EOF production site, there are between five (5) and nine (9) Mixing Ponds (MP), for a total of thirty-two (32), each MP with varying dimensions and production capacity. As part of the core functionality, the system calculates the total raw materials (RM) for each MP and aggregates total production across sites. As shown in Figure 5, a model DPSAT with six (6) MP (A, B, C, D, E, F) of distance (r) apart are connected to arrays of input (RM) sources including ash, cow dung, pig manure, plant residues, and poultry dung

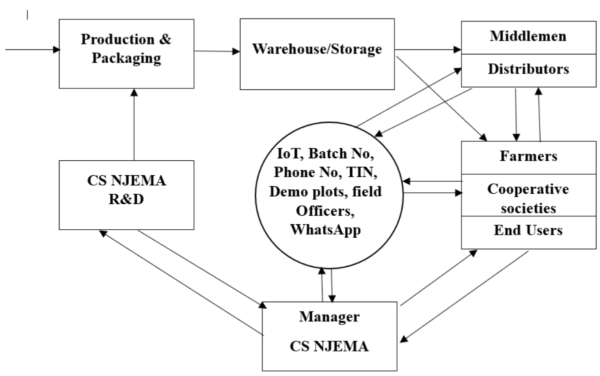

Figure 4: Feedback framework on the distribution and utilization of EOF.

and plant. The Biogas Slurry (BS) is injected into the various ponds through the Manholes (MH), each equipped with six (6) valves (V1-V6). The function of the MH is to collect the BS and send it through the valves (measured quantity of BS) into the MP in a controlled manner. MH and valves are opened and closed at different times, depending on which MP is receiving the inputs. The DPSAT was designed to respond to distress using Traffic Light System (TLS) principles involving Green (active), Amber (mature) and Red (inactive) with prompts which are attached to each of the MP. The PM prompts GREEN, when raw materials (ash, cow dung, pig manure, plant residues, poultry dungs and BS) are being added until saturation at the right proportions. The AMBER prompts signify maturation, and this begins when the last input (raw material) is added to the day's harvest of products (EOF). The RED prompts signify inactiveness of the pond. It escalates distress through alerts by prompting managers when raw materials (inputs) are in short or inadequate supply, lag in addition or the production ponds are completely empty.

DAPSAT Users' Roles and Responsibilities

1. Administrative Officer to handle the following
   a. Manages sites, ponds, users, and system settings.
   b. Views and generates reports for all sites together or filters reports by specific site.
   c. Monitors total raw material production across sites.
   d. Track fertilizer quantities in ponds, in the warehouse, packed, or sold.

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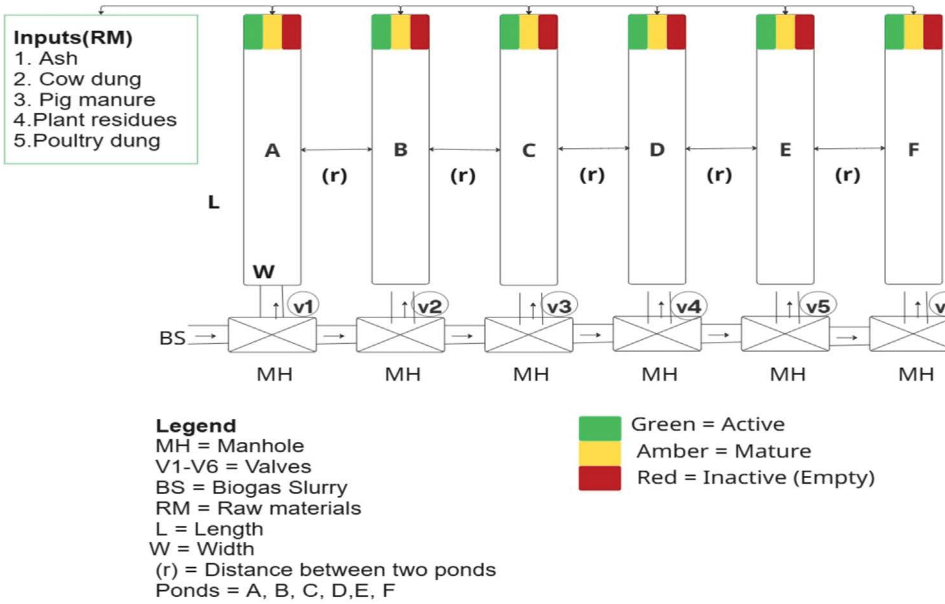

Figure 5: Automated model of organic fertilizer production mixing ponds.

2. Field Officer
    a. Enters pond and raw material data
    b. Records fertilizer bagging and stock updates
3. Manager
    a. Views reports and receives notifications, with the ability to see total production and fertilizer stock across all sites or per site.

Pond Status and Notification (High-level Automation Logic)

As shown in Table 3, four (4) activity series, including status update scheduler or notification service, maturation timer, total production, and fertilizer stock aggregations, have various responses (syntaxes). Accordingly, responses are logically run daily to check material presence and update MP statuses, triggers inform of distress when active MPs lack materials for seven (7+) days and above by sending SMS. Also, between 30 and 60 days after the last input is dropped, the system automatically changes from active status to maturation. The system also calculates total raw material per pond, site, all sites, and total fertilizer in the pond and in the warehouse (packed or sold).

Database entities and modular coding

As shown in Table 4, there are five (5) database entities (sites, ponds, raw material, fertilizer stock, and users) that operate with various modular coding. The site indicated modular code for the eight (8) default sites (locations of the EOF production facilities), while the ponds indicated three-dimensional (3D) measurements to reflect the volumes (length x width x height). The raw materials (BS, cow dung,

Table 3: Summary of Mixing Pond (MP) Automation Protocols.

S/No	Status/Activity	Notification/Prompt/Syntax
1	Status Automation/ Scheduler	Runs daily to check material presence and automatically update MP on maturation duration. Alerts with SMS notifications, e.g. when an active pond has no raw materials for 7 + days
2	Maturation Timer	Automatically changes pond from Active → Maturation after 30–60 days
3	Total Production Aggregation	Calculates total raw material per pond, site, and all sites.
4	Fertilizer Stock Aggregation, Tracking and Management	a. Manages stock of bagged fertilizer per site and pond.
		b. Records quantities and batch dates.
		c. Logs and tracks fertilizer movement from ponds to the warehouse packed, bagged, in progress, or sold.

Source: Author, 2026

pig dung, ashes, straw) are coded by total quantity and entry dates. The fertilizer stock is coded to reflect the quantity, status, date in, and date out. The modular coding for the users is identified through the name, role, phone number, and site.

The DPSAT Output and Protocol Definition

As shown in Table 5, ten (10) navigable dashboards interface of various relevance are displayed. The login page is essential for securing the web applications, and only authorized users can access data and sensitive controls. The System Users Interface enables users to view all system-generated reports in a single window and also provides functionality to input new data into the system. The site view gives users access to all site reports and view any specific site at any time. The portal for ponds dimension updates

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Table 4: Database entities and modular coding

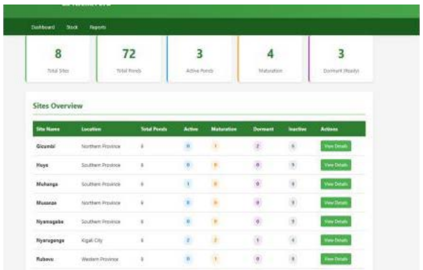
S/No	Entity	Modular coding operators
1	Sites	(id, name, location) – default 8 sites: Nyarugenge, Huye, Muhanga, Rwamagana, Nyamagabe, Musanze, Rubavu, Gicumbi.
2	Ponds	(id, site_id, name, length, width, height, status, last_updated)
3	Raw Materials	(id, pond_id, cow_dung, pig_dung, biogas_slurry, ashes, grasses, straw, total_quantity, entry_date)
4	Fertilizer Stock	(id, site_id, pond_id, quantity, status, date_in, date_out)
5	Users	(id, name, role, phone_number, site_id)

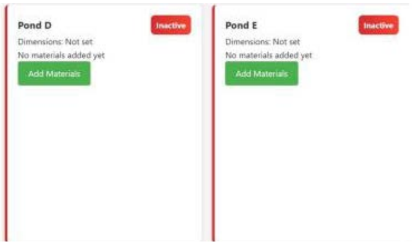
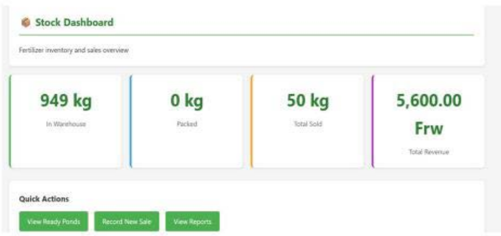
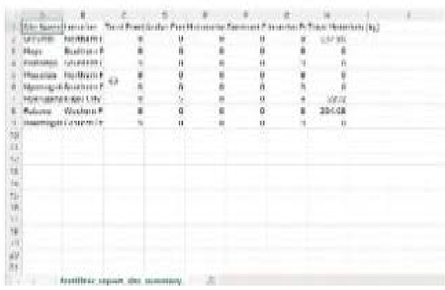
the dimensions (height, width, and length), and the system automatically calculates the volume. The portal for raw materials is the interface where the user can update the raw material for each pond. Ponds status is a web application that shows each pond status (active, mature, and inactive). Sales and inventory report, the system displays warehouse production, quantity sold, remaining stock, and the total cost. Production by site, the system can display the production by site. Exporting report, the system allows the user to export report in excel or Pdf format.

Discussion

Digital Protocol System and Automation Technologies (DPSAT) were designed to remotely monitor the current

Table 5: DPSAT outputs and protocol definitions

Dashboard/Navigation Pages	System output	Protocol Definition/Relevance
A login page		A login page is essential for securing this web application. It ensures only authorized users can access sensitive controls and data.
A system Users Interface		This user interface enables users to view all system-generated reports in a single window and also provides functionality to input new data into the system.
Site overview		Users can access all site reports and view any specific site at any time.
Portal for ponds dimension		The user can update the dimensions, height, width, and length and the system will automatically calculate the volume.

Portal for raw materials		The user can update the raw material for each pond
Ponds Status		This web application shows each pond status (active, mature, and inactive)
Pond status Cont…….		The application displays the pond status as inactive
Sales and inventory report		The system displays warehouse production, quantity sold, remaining stock, and the total cost
Production by site		The system displays the production by site
Exporting report		The system allows the user to export the report in Excel format or Pdf

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organic fertilizer production, distribution, production efficiency, farmer access, and utilization landscape of Eden Organic Fertilizers (EOF) in Rwanda. Using a functional web portal with authentication, the system monitors these activities across multiple sites by documenting the process of raw material handling, tracking pond statuses, reporting fertilizer stock, distributing, and receiving feedback from end users (farmers). The dashboard displays live pond statuses using color-coded indicators (green, amber, and red), and fertilizer data, including quantity and total number of raw materials. The status of each pond changes automatically over time based on raw material inputs.

It provides a concise technical Stock Management System (SMS) across various stages involved in the production of EOF. This starts from raw materials sourcing, pretreatment, composting, homogenizing, harvesting, curing, bagging, storage, and utilization by farmers. Using Create, Read, Update, and Delete-Application Programming Interfaces (CRUD APIs) for all entities, three (3) levels of Administrative Managers (AM) are programmed to hand the system from the field through the General Manager (GM), and directly to the Chief Executive Officer (CEO), and full report across all sites can be filtered by individual. Through the digital notification and reporting modules, all activities domiciled at every operational level can be seen by the CEO through the digital artery from the field and the GM (all AM), and when and where necessary, instructions are given to adequately respond to the distress prompted by the DPS. The distress may range from a lack of timely supply of input to the system, inadequate supply, empty ponds, or even an attempt to inject raw materials into the pond with impurities. Another log of distress is received when products are moved from the warehouse/store to the end users/farmers through detailed lodgments by the handlers. The signal at this point is either positive or negative to alert the GM on whether there is an addition or removal of products into or from the warehouse (Figure 5).

Global literature demonstrates successful applications of digital technologies in agricultural input management. Precision agriculture systems utilize sensors, GPS, and data analytics to optimize fertilizer application rates based on soil conditions and crop requirements [6]. This is what this research aligns itself with, using the DPSAT template in Rwanda.

Rwanda's organic fertilizer sector comprises diverse production systems ranging from household-level composting to commercial production facilities. Studies indicate that while farmers recognize the value of organic inputs, adoption remains below potential due to labor requirements, transportation costs, and perceived lower efficacy compared to mineral fertilizers [7]. CS NJEMA overcame these challenges through the DPSAT platform as a deliberate act, embracing digital technology holistically.

Again, in developing country contexts, mobile-based platforms have facilitated input distribution tracking and farmer advisory services, the implementation often faces connectivity and literacy barriers. In overcoming such setbacks, CS NJEMA Ltd, a certified leading organic fertilizer producer (EOF) in Rwanda, has bridged these gaps by adopting DPSAT. This is sacrosanct with the digitization effort of the Rwandan government as an emerging leader in digital transformation in Africa, with initiatives such as the Smart Rwanda Master Plan, where digital solutions have been deployed through platforms like the National Agricultural Export Development Board (NAEB) traceability systems and various mobile-based farmer advisory services [1].

With the deployment of DPSAT for EOF production, the proper formulation of ingredients (raw materials) in the right proportions, genuine composting, timely delivery, accountability, and product appraisal and feedback from farmers (end users) to company management are all done automatically (Figures 4 and 5).

The CS NJEMA invested in compost production infrastructure, including the establishment of demonstration farms and training programs. This is to ensure that the contentious issue of quality variability is no longer a persistent challenge, with certainty about the nutrient contents and no incessant reports of pathogen contamination. DPSAT beat the traditional monitoring which relies on visual inspection and periodic laboratory analysis, providing limited real-time quality assurance.

Looking into the future, CS NJEMA would be able to deploy blockchain technology, which has emerged as a tool for enhancing traceability and transparency in agricultural supply chains, with applications in fertilizer authentication and quality certification [8]. Also, the Internet of Things (IoT) sensors which enable continuous monitoring of composting parameters such as temperature, moisture, and pH, automating process optimization that traditionally required manual intervention is currently being deployed.

As recommended by Gebbers and Adamchuk [9], in the nearest future, CS NJEMA would extend services to include advances in soil testing through sensing technologies, using portable spectrometers and smartphone-based applications that would enable field-level nutrient assessment without laboratory analysis. Then, with integrated fertilizer recommendation algorithms, these tools would support site-specific nutrient management, potentially improving both productivity and environmental outcomes.

In the supply chain digitalization, the emphasis is on the role of digital platforms in reducing information asymmetries, improving coordination among stakeholders, and enhancing

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logistical efficiency. In fertilizer distribution specifically, digital systems have demonstrated the capacity to reduce counterfeit products, optimize inventory management, and improve last-mile delivery to smallholder farmers [10]. The details of clients (farmers, dealers, and cooperative societies), including their names, addresses, phone numbers, quantity purchased, quantity supplied, date issued, etc., are input into the DPS, which is transmitted across the board to all AM and finally to the CEO in a web-like manner (Figure 4). The Management routinely receives feedback from the end users of the EOF, either directly from farmers or indirectly through the Cooperative Society Manager (CSM) and Client Managers (CMs) of the company. The data generated through these cycles is promptly reviewed by the company (manager) to address missing products, client satisfaction, and overall appraisal. DPSAT is evolving, and where necessary, there would be improvements and upgrades.

Ethical Clearance Issues

All participants, including farmers, distributors, agricultural extension workers, and other stakeholders, voluntarily provided informed consent before participating in this research. Participants received clear information about the study's purpose, procedures, potential risks and benefits, and their right to withdraw at any time without penalty. All personal data collected during this research were handled in accordance with Rwanda's data protection regulations. Participant identities were anonymized in publications, and the research involves minimal risk to participants. Any potential risks related to the introduction of digital protocols and automation technologies have been assessed, and mitigation strategies have been incorporated into the research design. The research is designed to improve organic fertilizer production and distribution systems. Knowledge and technological innovations generated are expected to be shared with local communities and stakeholders. The research design respects local customs, traditional farming practices, and community structures, and was conducted in collaboration with local authorities and community leaders. The study incorporates environmental safeguards to ensure that organic fertilizer production, distribution, and utilization methods are sustainable and do not harm the environment or biodiversity.

Conclusion

This research contributes to the growing body of knowledge on digital agriculture applications in sub-Saharan Africa while addressing specific challenges in Rwanda's organic fertilizer value chain. By proposing scalable digital monitoring systems, this study offers practical solutions to improve input quality control, optimize distribution logistics, and enhance farm-level agronomic decision-making. The integration of DPSAT into organic fertilizer value chains represents a transformative opportunity for Rwanda's agricultural sector. By enabling real-time production monitoring, transparent distribution tracking, and data-driven utilization decisions, these systems address longstanding challenges of quality variability, limited farmer access, and inefficient resource allocation.

This research demonstrates that while implementation involves significant technical, financial, and institutional challenges, the potential benefits justify investment. Production efficiency gains, enhanced quality assurance, improved farmer access, and contributions to soil health objectives align with national agricultural transformation goals. Moreover, the data generated through comprehensive monitoring provides evidence for policy development and impact assessment.

As Rwanda advances its vision of agricultural transformation and climate resilience, digitally-enabled organic fertilizer systems will play an increasingly important role. The convergence of digital technologies, sustainable agricultural practices, and farmer-centered approaches creates pathways toward productive, resilient, and environmentally sustainable farming systems benefiting current and future generations.

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