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Importance of Smart Agriculture and Use of Artificial Intelligence in Shaping the Future of Agriculture

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

ABSTRACT

India, the second-most populated country globally with 1.4 billion people, faces significant challenges in its agriculture sector, including the need to feed a growing global population, mitigate climate change impacts, and ensure sustainable resource management. To address these

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challenges, innovative techniques and advanced technologies are required. Modern farming techniques, coupled with artificial intelligence (A.I.), offer promising solutions. Technologies such as drones, biotechnology, genetics, and precision farming can enhance efficiency, productivity, and sustainability. Implementing these approaches can lead to a fiftyfold increase in yield and a 50% reduction in manpower, contributing to increased crop yields, reduced water usage, minimized chemical applications, and improved labor efficiency. Smart agriculture holds the potential to revolutionize the industry, significantly contributing to global food security and the preservation of natural resources.

Keywords: Precision; drones; smart agriculture; robotics; regenerative.

1. INTRODUCTION

"The world's population is increasing and is expected to reach 10 billion by 2050 and food security has become one of the main issues of concern to the world. Simultaneously, due to the acceleration of urbanization, the land area available for agricultural cultivation is gradually decreasing. Labour shortages, frequent extreme weather and climate, and declining soil fertility have further brought tremendous obstacles to improving productivity" [1]. "All of these will exacerbate risks to food security. Currently, two ways to solve food shortages are to increase arable land or use modern technology to increase productivity" [2]. Meeting these demands requires innovation in farming, and the integration of Artificial Intelligence (A.I.) can play a pivotal role. Smart agriculture leverages cutting-edge technologies such as sensors, drones, satellite imagery, Internet of Things (IoT) devices, and A.I. to monitor, analyze, and manage farming operations. By utilizing real-time data and intelligent decision-making systems, smart agriculture aims to enhance productivity, reduce resource wastage, improve sustainability, and address the challenges posed by a growing global population [3].

"Modern technology represented by artificial intelligence (AI) began to be explored in agriculture in the last century. However, due to the limited technical level at that time, it brought little substantial progress. After entering the 21st century, the considerable effectiveness of AI in the industrial area has given agriculture new opportunities for change. Intelligent technology has gradually intervened in agricultural production, and promoting intelligence has become the mainstream agriculture trend. Smart agriculture (SA) uses modern industrial organizational methods, management concepts and advanced technologies to develop new concepts of modern agriculture, transforming traditional agriculture characterized by "land + machinery" into modern agriculture with "equipment + information + AI" as its core. The SA market was estimated at USD13.8 billion in 2020 and is projected to reach USD 22 billion by 2025 at a compound annual growth rate of 9.8%. Farmers can completely use relevant data sources to extract significant insights, regularities, patterns, and knowledge from accumulated data in order to create qualitative goods, enhance revenues, and make well-informed judgments. Big data is important in smart farming because it allows us to properly exploit this abundance of information" [4,5]. "Agricultural practices are currently utilizing comprehensive data analysis tools to intelligently and cost-effectively utilize smart farming data. Therefore, the adaptability of big data in smart farming analytics is demonstrated by a variety of common smart-farming applications. These examples show how big data may help farmers acquire useful insights and improve their farming methods" [6-9].

1.1 Environmental Data

"This category includes information related to climate conditions, soil properties, and water characteristics. Data on temperature, humidity, rainfall, soil nutrients, and water availability are some examples that fall under this category. Environmental data is crucial for making informed decisions about irrigation, fertilization, and pest control" [4,5].

1.2 Sensor Data

"Derived from IoT devices, robotics, satellite and drones, sensor data provides real-time information on various aspects of the farm. This data can include measurements of soil moisture, temperature, crop growth, and atmospheric conditions. IoT sensors play a significant role in monitoring and managing the farm environment efficiently" [4,5].

1.3 Agricultural Data

"This category involves data concerning both crop and livestock aspects of the farm. It includes information on plant growth, crop health, soil characteristics, as well as data related to animal well-being, weight, activity levels, and feeding patterns. Monitoring agricultural data helps optimize crop management practices, detect early signs of crop diseases, ensure proper nutrient management, and improve overall animal husbandry practices. Integrating and analyzing both crop and livestock data enables farmers to make well-informed decisions, enhance productivity, and achieve sustainable and efficient agricultural practices" [4,5].

1.4 Crop Data

"This category involves data specifically related to the cultivation and management of crops on the farm. It includes information on plant growth, crop health, soil characteristics, weather conditions, irrigation schedules, fertilization practices, and pest control measures. Monitoring crop data helps farmers optimize planting schedules, assess soil fertility, detect and address crop disease sand pests, and make data-driven decisions to enhance crop yields and overall agricultural productivity. Analyzing and utilizing crop data play a crucial role in implementing precision agriculture practices, conserving resources, and achieving sustainable crop production" [4,5].

1.5 Internet of Things

"Monitoring of the crop area in traditional farming calls for in-depth hard work, bodily equipment, time, and effort. It affords an opportunity to those conventional methods. An IoT of tool includes one or extra sensors that acquire records and offer correct data thru cellular programs or in different manners in real-time" [10]. "These sensors carry out infinite sports which include soil temperature and humidity sensing, plant and farm animal tracking, and extra. IoT additionally enables far-off tracking of farms, offering more comfort to farmers. Further, new irrigation structures make use of lot sensors to automate water transport to crops. These represent evapotranspiration sensors, on-web website online soil moisture sensors, and rain sensors, amongst others. Startups are growing modern sensor answers that integrate IoT era with drones, robots, and pc imaging to boom the agility, accuracy, and precision of farming processes. These ship on-time signals and enhance the reaction time for regions that want attention" [11,12].

1.6 Agricultural Robotics

Shortage of hard work is an important trouble face for farmers, and that is amplified in the case of massive area operations. So, startups are producing agricultural robots to help farmers in fruit-picking, harvesting, planting, transplanting, spraying, seeding, and weeding. Farmers are increasingly counting on robots to automate repetitive responsibilities within the area. They set up clever agricultural machines, which includes self-reliant and semi-self-reliant tractors for harvesting. Tractors additionally include vehicle mobile-steer era for simpler navigation throughout the area. Moreover, robots are utilized in automatic structures for farm animals' control as well. This consists of automatic weighing scales, incubators, milking machines, and vehicle mobile feeders. Robots permit farmers to consciousness extra on enhancing common productivity, while not having to fear approximately gradual farm processes. They additionally save you human-caused mistakes and offer comfort thru automation.

1.7 Artificial Intelligence

Artificial neural network and Machine learning algorithms have exhibited remarkable efficacy across diverse domains, exemplified by their prowess in character recognition [13] Nautiyal et al., 2018), image processing, and meteorological predictions. These capabilities can be extrapolated to agriculture, where they prove instrumental in disease recognition and the refinement of precision farming practices [3,5]. "Incorporating AI in agriculture affords farmers with real-time insights into their area conditions, letting them be proactive. Artificial intelligence technologies are the future of agriculture. Artificial intelligence can improve crop management practice and have potential to solve the challenges farmers face such as climate variation, an infestation of pests and weeds that reduces yields" [14]. "Artificial intelligence is also a tool extending our reach to think and store valuable data and information and use them effectively" (Ideaforge, 2020). "There is an ocean of opportunities in Artificial intelligence technology in the field of agriculture, from soil testing to crop monitoring. Some of the ongoing projects are doing so well that, some of them can even claim an augment of 30 to 35% in overall yield. Artificial intelligence technologies can be one of the major factors determining the scope of agriculture in the upcoming future. The use of Artificial intelligence is likely to bring about a revolutionary change in the field of agriculture. Machine learning is the current technology which is advantageous for the farmers as it helps them to mitigate the losses by providing methods of effective farming with the use of little manpower to produce high quality yield" [1]. "AI gives predictive insights for forecasting climate records, crop yield, and prices, thereby helping farmers to make knowledgeable decisions" [15]. Chatbots provide guidelines and enter hints to farmers. AI and ML algorithms automate anomaly and ailment reputation in flowers and farm animals. This allows well-timed detection and corrective reaction if required. Biotechnology additionally deploys ML algorithms for gene choice hints. Further, AI affords smooth get right of entry to finance to farmers who're denied credit scores from banks thru opportunity credit score scoring. Startups are exploiting AI in numerous approaches to give you modern answers that enhance common agricultural exceptional. For example, harvest exceptional vision is a current AgriTech innovation that scans and determines the exceptional amount of culmination and vegetables.

1.8 Drones

With so many uses and advantages, drone technology in agriculture is becoming more and more common. Drones are employed in remote sampling, livestock health monitoring, fertilizer and chemical spraying, and crop monitoring [16-18]. They can lower production costs and increase crop yield in precision farming, which is one application for which they are especially helpful [16]. Drone applications for agriculture have a bright future ahead of them, with room for growth and improvement [19]. Drones equipped with IOTs can play an indispensable role in upcoming Indian agriculture. Technologies like thermal scanning can play a very vital role in modern day agriculture [1]. Increasing farm productivity whilst saving expenses is challenging. But drones, additionally referred to as unmanned aerial vehicles (UAVs), assist farmers to triumph over this problem in a powerful way. Drones acquire uncooked facts which interpret into beneficial records for farm track. Drones prepared with cameras facilitate aerial imaging and surveying of close-to and far-stretched fields. These facts optimize the software of fertilizers, water, seeds, and pesticides, using precision agriculture. Moreover, drones facilitate farm animals tracking, geo-fencing, and grazing tracks. They fly over fields to seize photographs that vary from easy visible-mild snapshots to multispectral imagery which facilitates the crop, soil, and subject analysis. Even though drones aren't a match for fowl tracking as their motion frightens birds, drones are powerful for farm animal tracking, grazing tracking, and crop cultivation. Startups also are operating on drones able to measure the chlorophyll level, and weed pressure, in addition to soil mineral and chemical composition.

1.9 Precision Agriculture Sustainability in Agriculture

"It refers to the usage of green strategies and inputs that have 0 or minimum bad effects on the environment. An instance of that is site-unique crop and farm animal management, typically called precision agriculture. It is a way wherein farmers use specific quantities of input, along with water, pesticides, and fertilizers, to beautify the exceptional and productiveness of yield. Different tracts of land throughout the sphere have special soil properties, get hold of special sunlight, and feature special slopes. The identical remedy for the complete farm, thus, is inefficient and ends in a waste of time and resources. To address this, many AgriTech startups are growing answers in precision agriculture to enhance profitability whilst addressing sustainability challenges" [2].

1.10 Agricultural Biotechnology

Biotechnology plays an important role in agriculture by offering innovative solutions to improve crop production, enhance nutritional content, and reduce environmental impact. A lot of crop yield receives wasted because of pests and plant diseases. Although agrochemicals are applied in fields, they may be now no longer the first-class answer with regard to sustainability. On the opposite hand, the utility of biotechnology in agriculture improves the exceptional of vegetation and farm animals. Scientific strategies like plant breeding, hybridization, genetic engineering, and tissue lifestyle facilitate the identity of higher developments in flowers. CRISPR-Cas9 is a genome-modifying era that permits excessive goal specificity with stepped-forward velocity and precision. It produces transgenic flowers with preferred features like ailment tolerance, drought tolerance, pest resistance, and excessive yield capacity. This complements the profitability of farm production. Startups additionally leverage agri-biotech strategies to offer answers along with biopesticides, bioherbicides, biofertilizers, and bioplastics for fields. These answers deal with soil toxicity worries and make certain a minimum bad effect on the environment. Here are some key ways in which biotechnology contributes to agriculture:

1. Genetic modifications of crop
2. Crop protection
3. Disease and pest management
4. Crop improvement and yield enhancement
5. Nutritional enhancement
6. Sustainable agriculture and environmental impact Precision farming.

1.11 Big Data and Analytics

Big statistics and analytics strategies rework normal farm statistics into actionable insights. Statistics of crop area, production, land use, irrigation, agricultural prices, climate forecasts, and crop diseases, lay the inspiration for the following farming season. Analytical gear employ statistics [20]. Analytics and statistics play a vital role in agriculture by providing valuable insights and informed decision-making to optimize farming practices. Here are some key applications of analytics and statistics in agriculture:

1. Yield forecasting
2. Crop monitoring and yield detection
3. Irrigation optimization
4. Precision nutrient management
5. Market analysis and price forecasting
6. Risk assessment and Management
7. Resource optimization

Overall, the use of analytics and statistics in agriculture enables farmers to make data-driven decisions, optimize resource allocation, reduce risks, improve productivity, and promote sustainable farming practices. These tools are instrumental in addressing the challenges faced by the agriculture sector and ensuring food security in a rapidly changing world.

1.12 Sensor-Cloud Computing

The on-field WSN applications that are supported by cloud computing are referred to as sensor-cloud computing [21]. The higher processing speed and storage capacity of this integrated framework help WSNs. Additionally, sensor-cloud increases resource usage while enhancing data management and access control. Several potential uses for the agricultural domain include

1. it is necessary to establish a cloud-enabled. storage system for the spatial fluctuation of soil and environmental profile with regard to different seasons.
2. utilizing mobile sensor-cloud services to monitor crop health and anticipate yield.
3. creating a smart irrigation system for big fields that is sensor cloud controlled.
4. to create a sensor-cloud controlled environment control system for greenhouse farming's off-season production of crops and flowers.

1.13 Livestock Monitoring

Using sensors, GPS, and other technologies, an innovative system for monitoring cattle has been created [22]. It combines all of these technologies with a network protocol for communication. This monitoring equipment allows the farmers to check on their farm animals from a distance. The tracker device, which can be attached to collars, can keep an eye on things like animal health, chewing patterns, location data, pasture management, etc. The management of farm animals and other agricultural equipment is made easier with the help of the livestock monitoring system. The infrastructure for tracking cattle that is IoT-enabled may end up being quite helpful for livestock production. IoT-enabled livestock management solutions give information on a variety of aspects of cattle health. A wearable collar or tag with sensors is used to monitor the position, temperature, blood pressure, and heart rate of the animals, and the information is wirelessly transmitted nearly instantly to the farming machinery the cattle are connected with base station by using Radio-frequency identification (RFID). There are IoT Dashboards, online apps, and mobile applications to connect to base station for collecting sensor information from user end. Farmers may safeguard the areas where the cattle are permitted to roam freely by setting up geofencing using the app that comes with the device.

1.14 Controlled Environment Agriculture

Fluctuating and intense climate activities continuously bog down traditional farming techniques. Further, developing plants in populated cities, deserts, or different detrimental situations pose substantial challenges. This is conquered with the aid of using managed surroundings agriculture (CEA). In CEA, plant life is subjected to a managed percentage of light, temperature, humidity, and vitamins. There are specific developing environments, namely, indoor farming, vertical farming, and greenhouses, amongst others. There is an improved deployment of strategies like hydroponics and aeroponics which contain developing soilless plant life in a liquid nutrient medium or steam. Another such approach is aquaponics, in which plant life and fish are cultivated simultaneously. Fish offers vitamins to plant life even as plant life purifies the water for the fish. CEA techniques lessen pests and diseases, grow yield, and set up sustainable farming practices.

1.15 Regenerative Agriculture

According to Pretty [23] and Savory [24], regenerative agriculture is a sustainable method that stresses the integration of renewable resources and the use of low-external input technology to increase agricultural productivity. As Giller [25] points out, this approach is especially pertinent in light of the current agricultural crisis. Giller also warns against the one-size-fits-all approach and stresses the importance of context-specific approaches. Pretty (1995) emphasizes the significance of laws and methods that support agriculture's self-sufficiency and sustainability even further. “Regenerative agriculture has the potential to have a powerful beneficial impact on a number of these global concerns. Regenerative agriculture, on the other hand, has the potential to strengthen supply chains, restore biodiversity, equitably distribute land value and access, and enable farmers, businesses, and communities to prosper” [26]. Conventional farming practices result in long-time period erosion and crusting of soil. Often, the ploughing, tilling, and overgrazing don’t permit a good deal of time for the soil to restore earlier than the subsequent cropping season. Regenerative agriculture, on the opposite hand, has reasons for minimum soil disturbance even specializing in enhancing soil biodiversity and topsoil revival. It includes specific practices like no-until farming, decreased tillage, crop rotation, and extra. For example, cowl plants are planted to cowl the soil during cropping seasons to repair soil fertility. Further, regenerative farming helps fields to behave as a carbon sink thru sequestration. This ends in fewer carbon emissions into the environment and a lesser effect on weather change. Regenerative agriculture is considered to carry the potential of achieving "farming with zero carbon" or even decreasing emissions of GHG from other industries [27]. Moyer et al., [28] found that adoption of regenerative globally taps in both grasslands arable and grasslands areas more than 100% may be captured of current emission of man produced CO2. Other proponents of Regenerative Agriculture quickly shattered this assertion.

1.16 Connectivity Technologies

“Smart farming isn't viable without connectivity technology like 5g, LPWAN, rural broadband, or satellite-enabled communication. 5G helps the adoption of IoT devices, robots, and sensors and allows them to talk at excessive speeds. This allows farmers to reveal the facts extra correctly in real-time and take the specified actions. High-velocity net the usage of fibre optic cables resource the trade of subject facts in real-time, that's important in terms of enhancing accuracy. Connectivity technology helps different technology like IoT, which in the long run paintings in coordination to shape related farms” [29].

2. WIRELESS COMMUNICATION TECHNOLOGIES FOR SMART AGRICULTURE

“Different type wireless protocols and standards used in agriculture are ZigBee Wireless Protocol, Bluetooth Wireless Protocol, Wi-Fi Wireless Protocol, GPRS/3G/4G Technology, Long Range Radio (LoRa) Protocol and SigFox Protocol. These wireless technologies are also compared to identify the most convenient technology in terms of power consumption and communication range, where the two metrics are posed challenges in current solution of agricultural application. IoT is a revolution for the future realm where everything that can utilize a connection will be connected. Cellular technologies are grown and developed to play a crucial role in the IoT” (Carolam 2022).

2.1 ZigBee Wireless Protocol

One of the leading technologies for the farming and agriculture industries is the ZigBee wireless protocol. ZigBee is thought to be suitable for PA applications including irrigation monitoring [30], water quality management, fertilizer and pesticide control due to its low duty cycle, all of which require for cyclic information updates. The sensor nodes in the agricultural field can interact with the router or coordinator node over a great distance due to this technology (i.e., 100m). Additionally, ZigBee can shorten the connection distance indoors by up to 30 metres (i.e., greenhouses) [30].

2.2 Bluetooth Wireless Protocol

A communication link between mobile and portable devices, such as laptops, has been established using the Bluetooth (BT) standard over a short distance of up to 10m. Given its widespread use and accessibility on most mobile devices, BT has been used to meet many agricultural requirements. Global Positioning System (GPS) and BT technologies are used to remotely monitor weather data, soil moisture, sprinkler position, and temperature. The irrigation application described in [31] was created to improve agricultural productivity and conserve water. The irrigation application suggested in [32] uses the BT wireless connection protocol to gather field data in real-time. Based on BT, several pieces of software and hardware were created in [33] to track the temperature and relative humidity in greenhouses.

2.3 Wi-Fi Wireless Protocol

The most extensively used wireless technology in portable devices right now, including tablets, smartphones, laptops, and desktops, is Wi-Fi. In both indoor and outdoor settings, Wi-Fi has a sufficient communication range of roughly 20 m and 100 m, respectively. Wi-Fi enhances several designs in PA applications by establishing an ad hoc network connection between various sorts of devices. Under 3G and Wi- Fi connection settings, the feasibility of wireless remote monitoring and control of a protected agricultural environment using mobile phones was assessed in (Chung et al. 2015). Before being sent through a Wi-Fi network to the server computer, agricultural data such as soil temperature, soil moisture, weather temperature and humidity, sunshine intensity, and CO2 were stored in a gateway [34]. For monitoring agriculture, Mendez et al. [35] suggested a Wi-Fi based smart WSN which included sensor, router, and server for three nodes. The humidity, temperature, air pressure, light, water level, and soil moisture of the greenhouse or agricultural field are all kept under observation by using the system. Mentioned effort aims to increase the mobility and flexibility of the sensing points in WSN while lowering the cost and number of wiring connections. The proposed system's 42.17 J/h energy usage is rather high, though.

2.4 GPRS/3G/4G Technology

Based on data gathered by temperature and soil moisture sensors implanted at the root zone of plants, Gutiérrez et al. [36] developed an automatic crop irrigation system using the GPRS module and WSN. This system was considered a realistic and affordable way to improve water quality. Ruirui et al., (2010) used soil moisture to evaluate a drip irrigation system by using an energy-efficient wireless sensor network. A prototype system was also created in the study based on data management server and a WSN-GPRS gateway. Navarro Hellín et al., (2015) used various wireless nodes with GPRS to communicate data about the soil, plants, and atmosphere. To gather agricultural information, all sensors are interfaced to the sensor board. Such data is communicated via the GPRS-board, which is dependent on a GSM/GPRS mobile network, to the remote server for additional processing.

2.5 Long Range Radio (LoRa) Protocol

The LoRa gateway can communicate with a cloud server over a large communication range and with high scalability by gathering data from LoRa nodes to build the topology of a star network. Gil-Lebrero et al., [37] used LoRa wireless protocol in order to monitor bee colonies in rural locations and to ensure communication between the bee node and the local server, which is situated in a remote location. Utilizing various sensors, microcontrollers, and the LoRa wireless protocol, the soil moisture and temperature, the air temperature and humidity, and the light intensity inside greenhouses were also monitored [38].

2.6 SigFox Protocol

The low data rate applications of SigFox's ultra-narrowband wireless cellular network make it suitable for IoT and machine-type communications systems. Numerous applications, including telephone, security, mobile, broadband, and television, have made use of SigFox. In [39,40] a geolocation system that localizes animals in mountain pastures throughout the summer was built using the SigFox network [14,42].

3. CHALLENGES IN SMART AGRICULTURE

The higher cost of sensors and associated parts, spatial diversity in local climate and soil condition, segmented land area,and individualized designing system for small scale farmers are the special hurdles in applying agricultural smart technology under Indian situations. Therefore, the factors related with the smart technology that needs further attentions in the future as mentioned below [43,44].

1. **Cost:** A cheap solution is generally preferred to broaden the applications' reach and scope.
2. **Autonomous operation:** In the future, systems should be designed with the ability to support autonomous operations for an extended period of time.
3. **Intelligence:** An inherent intelligence that will allow futuristic solutions to respond quickly to a variety of problems, from energy conservation to real-time response.
4. **Portability:** The system must be portable for ease of application. System in package (SiP) and System on Chip (SoC) technologies, two recent developments in embedded systems, will be helpful in this area.
5. **Low maintenance:** It's important to create a system that requires the least amount of maintenance work. Over time, this will unquestionably reduce the average cost.
6. **Energy-efficiency:** The solutions must be more energy-efficient by implementing intelligent algorithms in order to guarantee extended lifetime with autonomous functioning.
7. **Robust architecture:** To ensure continued operation, developing applications need a robust and fault-tolerant architecture.
8. **Operational simplicity:** Non-technical people are typically the apps' end users. Therefore, these programs must be easy and simple to use.
9. **Interoperability:** The system's overall functionality will be improved by the ability of various components and communication technologies to work together seamlessly.

4. CONCLUSION

Despite being underutilized artificial intelligence in agricultural sector seems to have a bright and promising future and the upcoming results may be ground-breaking. The use of A.I. has a lot of potential and is the future of agriculture. A.I. will assist farmers in finding better jobs and thus, improving their quality of life. It can reduce the manpower needed in agriculture as compared to traditional methods. Overall, the application of scientific knowledge and technology to agriculture is essential for addressing the challenges of food security, sustainability, and environmental stewardship in a rapidly changing world. Smart agriculture is a revolutionary strategy that uses technology to improve agricultural practices and tackle industry problems. Smart agriculture provides several advantages and prospects for farmers, the environment, and food production as a whole by combining multiple technologies including IoT, artificial intelligence, and data analytics. Increasing production and efficiency in agriculture is a major benefit of smart agriculture. Farmers may monitor and improve a number of characteristics, including soil moisture, temperature, and nutrient levels, by using sensors and linked devices. With the use of this real-time data, knowledgeable decisions can be made that result in timely pest management, precision watering, and targeted fertilizer delivery. Crop yields may be increased and resource utilization can be minimized as a consequence, which will ultimately result in more profitability and lower environmental impact.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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