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AI AND IOT-DRIVEN SOLUTIONS FOR SUSTAINABLE FARMING IN PUNJAB: OVERCOMING FINANCIAL BARRIERS AND ENHANCING RESOURCE EFFICIENCY

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ABSTRACT
One of the most important industries in the world today is agriculture, which is essential to environmental sustainability, food security, and economic growth. With a growing global population expected to reach nearly 10 billion by 2050, ensuring a steady and reliable food supply is essential for avoiding hunger and malnutrition. Once called as 'granary of the country' and 'bread basket of the country', the state of Punjab revolutionized the Agro needs and Agro economy of the country, after the green revolution, Punjab, Haryana, and western UP quenched the need for food security and got India independence from the humiliating PL480 scheme. Punjab contributes 10 - 12 % of rice and 13 - 15 % of wheat in India's total rice and wheat production despite covering only 1.5 % of the geographical area of the country. After the Green Revolution. People employed in agriculture and agriculture-related fields have drastically come down from 60% to 35-36%, and that is not just because of modernization, urbanization, and diversification rather Many people have lost interest in farming as a result of Punjab's diminishing agricultural economic returns, soil deterioration, and the depletion of natural resources like groundwater. Traditional crops like rice and wheat have yielded stagnant income over time, and the rising labor, fertilizer, and water costs have made farming less profitable. Many farmers in the state suffer from poor and erratic profits as a result. The frequency of farmer suicides in Punjab has jumped since 2015. From nearly 70 suicides a year between 2000 and 2014, the number increased by nearly four times to 263 a year after 2015 (peaking at 323 in 2018).[The India Forum]. Many of the reasons farmers take these extreme steps can be improved with the use of AI and IoT-incorporated farming. The adoption of advanced technologies like agricultural sensors, drones, GPS, and other integrated devices has rapidly progressed in agriculture. However, in Punjab, most farmers have not embraced these precision agricultural practices. Key reasons include a lack of awareness about these technologies, financial constraints, and other practical barriers that limit farmers' ability to implement modern farming methods. In this paper, writers have addressed the major problems farmers across Punjab are facing and how many of these can be solved using modern technological approaches.

KEYWORDS: Agriculture, Sustainability, Internet of Things, and Artificial Intelligence.

INTRODUCTION
Punjab's headlines today center on the state's dwindling water table, deteriorating irrigation and potable water quality, declining agricultural profits and growing farmer debt, declining productivity, and deteriorating natural resource quality (soil, water, and climate). Real estate is consuming the state's valuable agricultural grounds, which is another concerning development. The largest reactors on Earth are soil and water, which are the sites of the majority of physical, chemical, and biological interactions. Additionally, these are the biggest sinks, where the majority of garbage from industry, agriculture, humans, and animals is dumped. When the extent of detrimental processes is growing and the earnest attempts of professionals are failing to end the agricultural productivity standstill.

With a vast irrigation system and 84% of its 5.036 million hectares under cultivation, Punjab is a region in the Indus basin. 97.4% of the net sown land was irrigated in 2005–06; canals accounted for 23% and tube-wells for 73% of this irrigation. The state still has a serious water scarcity in spite of this infrastructure. 65% of active holdings are small farms with less than 4 hectares, and Punjab contributed a sizable portion of India's wheat, rice, and cotton despite making up only 1.53% of the country's total land area. During the Green Revolution, the state's position as the "food basket of India" was solidified because of improved irrigation, high-yield crop types, land consolidation, and government assistance through minimum prices and procurement.

Due mostly to an overreliance on groundwater, Punjab's water constraints have gotten worse as rice farming has spread to non-traditional locations. Thus, from 3% in 1973 to over 90% in 2004, the water table depth below 10 meters has increased. According to a recent report, the state's water table is currently below 15 meters, which poses a major risk to agriculture in the future. Punjab's agricultural practices must be reoriented to solve these issues, with an emphasis on sustainable resource management, long-term planning centered on natural resources, and an all-encompassing approach to land use and agricultural technology. Punjab's agrarian crisis is caused by a confluence of social, environmental, and economic problems. Let's see some major issues:

Depletion of Groundwater and Water Scarcity

Water constraints in Punjab have gotten worse as a result of the expansion of rice farming, particularly in regions that have not historically been used for this water-intensive crop. This need has resulted in significant abuse of groundwater. The percentage of land with a water table deeper than 10 meters increased from 3% to over 90% between 1973 and 2004, and levels have now dropped below 15 meters in many areas, indicating a serious water dilemma for agriculture's future [1].

Degradation of Soils with Intense Farming

Although the Green Revolution of the 1970s increased crop production at first, soil health deteriorated because of its heavy reliance on chemical pesticides and fertilizers. This method produced nutrient-poor soils that have grown more reliant on expensive fertilizers. As a result, soil fertility has decreased, making it challenging to produce sustainably [4].

Excessive Debt

Farmers are facing severe financial hardship as a result of rising input costs for things like seeds, fertilizer, and insecticides. Many farmers resort to high-interest loans from informal lenders, leading to high levels of indebtedness. This financial burden has contributed to the tragic reality of farmer suicides, with around 1,806 suicides recorded between 2012 and 2023 as a result of debt[12].

Expensive Fertilizer

Global price swings and growing production costs have caused fertilizer prices to rise dramatically over time. Due to this increase, fertilizers are now among the most costly inputs for Punjabi farmers, who depend significantly on them to maintain high yields in their wheat and rice crops. Due to supply chain interruptions, rising energy costs, and geopolitical conflicts affecting the availability of raw materials, fertilizer prices have grown, particularly in recent years.

Punjab's dependence on chemical fertilizers to increase productivity increased during the Green Revolution. Because the soil's natural fertility has been weakened by constant use, yields have decreased and it now requires significantly more fertilizer to sustain yields [16].

IOT AND AI-ORIENTED SOLUTIONS

Why Farmers of Punjab Need A Solution to Depleting Water Cycle

The falling water table in Punjab, India, poses serious problems for farmers and has far-reaching social and economic repercussions. Farming costs are greatly increased, particularly for small-scale farmers, by the growing cost of irrigation, which is fueled by the requirement for deeper wells and more energy-intensive pumps [1]. Crop yields are impacted by declining water availability, especially for water-intensive crops like rice, which lowers agricultural output and increases food insecurity. Furthermore, excessive groundwater withdrawal has caused soil salinization [2], which lowers soil productivity and fertility even more. Due to farmers leaving agriculture in pursuit of greater incomes, this crisis has also exacerbated unemployment and put strain on urban infrastructure by encouraging rural-to-urban migration. Social tensions in the area are exacerbated by local conflicts over diminishing resources and interstate water issues [3].

A solution to groundwater depletion

By facilitating more effective use of water in agriculture, artificial intelligence (AI) and Internet of Things (IoT) technologies can be crucial in resolving Punjab's groundwater depletion issue. These technologies can be useful in the following ways:

AI-Based Precision Agriculture Optimizing Irrigation: To identify the best irrigation schedules, AI algorithms may evaluate a variety of data points, including crop water requirements, soil moisture levels, and weather forecasts. This guarantees effective water use, avoiding overwatering and lessening dependency on groundwater.

Water Demand Predictive Analytics for Crops: By taking into account environmental factors, past weather patterns, and soil health, machine learning models are able to forecast the water requirements of crops at various stages of growth. This can assist farmers in making data-driven, real-time irrigation decisions, lowering.

Smart Irrigation Systems Powered by IoT

Soil Moisture Sensors: Farmers can receive real-time data from IoT-based sensors buried in the soil that continuously measure moisture levels. By ensuring that water is only used when necessary, these sensors cut down on waste and stop groundwater resources from being over-extracted.Water may be precisely provided to crops according to their unique moisture requirements by attaching these sensors to automated irrigation systems. This enables farmers to use less water while preserving crop health.AI systems can combine real-time information from satellites, weather stations, and Internet of Things sensors to give farmers a complete picture of the water condition of their land. This makes it possible to make well-informed decisions on resource management and irrigation.

Drone Monitoring: Large agricultural fields can be monitored for soil moisture, crop health, and overall water use efficiency using drones fitted with sensors. By gathering information, these drones can improve irrigation techniques

and guarantee more sustainable water use.To track water usage in real time, IoT-based water meters can be placed at strategic locations within irrigation systems. By identifying areas of excessive use, this data may be evaluated to help regulate water distribution and guarantee that resources are used effectively.

AI-Based Water Delivery Optimization: AI is able to optimize water distribution across fields by taking into account variables including crop needs, soil health, and water availability. This keeps crop yield high while lowering reliance on groundwater.

Why farmers of Punjab need a solution to soil degradation

Punjab's farmers face severe financial difficulties as a result of soil deterioration, which affects not only the farming industry but also the larger agricultural sector. Crop yields are directly lowered by declining soil quality, especially in areas with nutrient depletion and water shortages, which makes farming less lucrative and requires more resources. Farmers must make significant investments in fertilizers and soil amendments when soil fertility declines over time in order to sustain production levels. Due to the increased production costs and potential for a vicious cycle of decreasing returns, this reliance on chemical inputs eventually lowers farmers' net income and may even cause some to give up farming entirely.

Farmers in Punjab are impacted by soil degradation in different ways depending on the location because of differences in agricultural techniques and environmental circumstances. Because intensive farming depletes soil nutrients in central Punjab, where rice-wheat cycles are frequent, farmers must use expensive fertilizers to sustain a yield, which lowers earnings (Singh & Benbi, 2017; Joh & Chibba, 2002). Due to extensive groundwater use, southwestern Punjab experiences problems with soil salinity and alkalinity, which restricts crop alternatives and raises farming expenses (Benbi et al., 2006). Because of the soil erosion caused by the steep terrain in northern Punjab, conservation efforts are both required and expensive, with financial returns frequently falling short of these costs (Nayyar et al., 2001).

A solution to soil degradation

By facilitating more focused and effective soil management techniques, AI and IoT can be extremely helpful in tackling Punjab's soil deterioration. In order to maintain and restore soil fertility, farmers can use these tools to track soil health, optimize inputs, and make data-driven decisions. Here are some ways that IoT and AI might help manage soil deterioration locally

IoT Sensors for Soil Health: Real-time information on temperature, pH, nutrient content, and soil moisture levels can be obtained using IoT-based soil sensors. Farmers can identify early indicators of soil deterioration, such as nutrient deficiencies or abnormal pH levels, which are prevalent in areas that rely significantly on chemical fertilizers, by regularly monitoring these parameters.

Precision Nutrient Management: Using data from soil sensors, AI may prescribe targeted fertilization based on the state of the soil. Ensuring that nutrients are administered only when and where they are needed, helps prevent misuse of fertilizers, which is a typical cause of soil acidity and nutrient imbalance.

Drone Surveillance: Soil erosion may be mapped over wide areas using drones fitted with multispectral sensors. These drones can identify areas at risk of erosion by taking precise pictures and analyzing topography, vegetation cover, and soil texture.

AI-Driven Erosion Models: AI is able to generate prediction models of soil erosion by processing data from IoT sensors and drones. These models may predict erosion-prone areas based on land slope, soil type, and weather patterns. Farmers can stop future degradation by identifying these areas and implementing soil conservation techniques like terracing, contour farming, or cover crop planting.

Artificial Intelligence (AI) for Fertilizer Recommendations: By analyzing soil data, AI systems can provide personalized fertilizing schedules, minimizing the overuse of chemical fertilizers. This lessens the long-term loss of vital nutrients in the soil, which is a frequent problem in regions with intense farming, like Punjab, and helps restore soil fertility.

Composting and the Management of Organic Matter: IoT devices are able to track the amount of organic matter in the soil, which is essential for preserving soil fertility and structure. In regions where excessive monoculture farming is causing soil degradation, AI may evaluate this data and suggest applying organic supplements, such as compost or green manure, to improve soil health.Waterlogging and soil salinity are two consequences of excessive irrigation that lower soil quality. When combined with artificial intelligence (AI), IoT-enabled smart irrigation systems may guarantee that water is supplied precisely when and where it is needed, depending on weather and soil moisture levels. This keeps water from being wasted and keeps the soil from getting too wet or salty.

Why farmers of Punjab need a solution to debt and payment crisis

Growing input prices for basic agricultural commodities like seeds, fertilizer, and pesticides are putting a heavy financial burden on Punjab's farmers. Small and marginal farmers have found it challenging to keep steady crop profits as a result of these price rises. The issue is made worse by the

scarcity of reasonably priced institutional credit, which forces many farmers to turn to unofficial moneylenders for exorbitant interest rates in order to cover their expenses [12]. Many farmers are caught in a debt cycle as a result of their reliance on high-interest loans. Farmers find it difficult to repay these loans when crop yields or prices fall short of expectations, which causes debt to grow to an unmanageable level. The Punjab Farmers' Commission claims that one of the main causes of agricultural hardship has been financial turmoil.According to the Punjab Farmers' Commission, one of the main causes of farmer suicides has been financial hardship; from 2012 to 2023, 1,806 suicides were reported in the area as a direct result of debt [13].

A solution to reduce debt and dependency on high interest loans

By enhancing financial access, streamlining farming methods, and facilitating data-driven decision-making, artificial intelligence (AI), the Internet of Things (IoT), and automation help alleviate Punjab's farmers' financial struggles, particularly in light of high-interest informal loans. Through increased financial transparency, improved credit accessibility, and decreased input costs, these technologies can lessen reliance on unofficial money lenders. Here's how:

By developing reliable credit rating systems specifically for farmers, AI can make it easier for people to obtain financing at reasonable rates. Due to their lack of official financial records, small farmers are frequently left out of traditional credit rating models. To determine a farmer's creditworthiness, AI can examine non-traditional data elements including farming history, crop yields, weather patterns, and even social conduct [14]. To further improve credit risk assessments, AI models can also be combined with IoT data from agricultural operations, such as yield forecasts, crop growth, and soil health. The demand for informal loans may decline if farmers have improved access to official financial services, which would help end the debt cycle and lessen financial strain. The government of open access. Precision Farming to Reduce Input Expenses Farmers may lower their overall expenses by optimizing their usage of inputs like seeds, fertilizer, and water with automation and Internet of Things sensors. Based on current conditions, AI systems may evaluate data from Internet of Things sensors to suggest exact dosages of pesticides, fertilizer, and water. This lessens waste and makes sure farmers aren't spending more than they need to, which may lessen their dependency on loans [15]. Additionally, AI-powered platforms can offer customized risk management resources including crop insurance, pest and disease forecasting, and weather forecasting models.Farmers can take preventative action by using real-time data on temperature, soil moisture, and other important variables from IoT devices. Furthermore, using weather patterns and satellite data, AI can automate the process of giving crop insurance, assisting farmers in risk management and securing their livelihoods without the need for costly informal loans. Farmers may decide when to sell their produce by utilizing AI to forecast crop prices based on supply-demand dynamics, weather patterns, and market trends. By doing this, farmers are protected from having to sell their produce at a loss [15]. By removing middlemen like unofficial lenders who impose high interest rates, artificial intelligence (AI) can assist farmers in obtaining transparent, equitable financial transactions. By using blockchain technology, farmers might bypass the predatory practices of informal financing and directly access government programs, subsidies, and loans with clear terms. The decentralized structure of blockchain also improves trust and lowers fraud, which might be especially helpful in rural areas with weaker financial institutions [15].

Why farmers of Punjab need a solution to rising fertilizer prices

The rising cost of fertilizers is significantly affecting Punjab's farmers, leading to increased production costs, financial stress, and a cycle of debt. Fertilizers, crucial for maintaining soil fertility in intensive farming systems like wheat, rice, and cotton, have become increasingly expensive due to global price hikes and reduced domestic subsidies. This escalates production costs, and many farmers, particularly in regions like Malwa, are unable to afford the required quantities, leading to reduced yields and poor soil health[16].

To cope with rising input costs, farmers often turn to informal money lenders, incurring high-interest debts that become difficult to repay due to fluctuating crop yields. This indebtedness has contributed to an alarming rate of farmer suicides, particularly in areas like Doaba, where rice cultivation heavily depends on fertilizers[17].

The impact of rising fertilizer prices varies across different regions of Punjab. In monoculture-heavy regions like Doaba and Majha, the high dependence on fertilizers for crops like rice and wheat exacerbates soil degradation, with rising costs making it harder to maintain soil health [18]. In contrast, regions like Malwa, though more diversified in crops, also face significant financial challenges due to these price increases. These financial pressures, coupled with the rising costs of essential agricultural inputs, continue to threaten the economic stability of farmers across the state, highlighting the need for sustainable agricultural practices and improved financial support systems

A solution to reduce the cost of fertilizers: Punjab's farmers can greatly benefit from AI and IoT in overcoming the difficulties brought on by high fertilizer prices, debt, and financial strain. By facilitating precision farming, increasing

financial inclusion, and optimizing input utilization, these technologies lessen the demand for unofficial credit and increase the financial stability of farmers. Here is a summary of how IoT and AI might help with these problems in Punjab's several regions:Precision agriculture is one of the main ways AI and IoT may assist farmers in lowering the cost of fertilizer. Real-time information on soil pH, temperature, moisture content, and nutrient levels can be obtained from Internet of Things sensors buried in the ground. Making educated decisions on the application of fertilizer requires this data [19]. AI-driven nutrient management systems can accurately monitor soil health and lessen dependency on chemical fertilizers, which lowers input costs in areas like Majha and Doaba where rice and wheat production significantly depends on fertilizers. AI-based models can also forecast when fertilizer should be applied based on soil conditions and weather forecasts, ensuring that farmers only apply fertilizer when necessary to maximize crop yields and minimize waste [20]. By offering different credit scoring models, AI can also improve farmers' access to loans. Due to their lack of credit history, many farmers in Punjab are unable to obtain official loans. In order to provide a more thorough assessment of a farmer's creditworthiness, AI may evaluate non-traditional data points like farming history, weather data, and crop yields. Farmers can obtain tailored lending offers with reduced interest rates by combining AI and IoT data (such as soil moisture levels and crop growth forecasts), which lessens their reliance on unofficial money lenders.AI can develop customized financial models based on the unique needs of various crops, assisting farmers in Malwa, which struggles with a variety of cropping patterns, in obtaining loans at reasonable interest rates [21]. Waterlogging and salinity brought on by excessive irrigation can worsen soil health and lower crop yields. By offering real-time information on soil moisture levels and weather forecasts, IoT-enabled smart irrigation devices can assist Punjabi farmers in effectively managing their water use. Water waste and soil salinization can be avoided by using AI algorithms to improve irrigation schedules and make sure that water is only utilized when needed. In Malwa, where irrigation plays a significant role in agriculture and water resources are scarce, smart irrigation can improve soil health, cut down on water use, and save money by avoiding over-irrigation. Additionally, these methods can be modified for Doaba and Majha, which are home to water-intensive crops like rice [20].

Barriers to implementation of AI and IoT in Punjab agriculture

Punjabi farmers encounter a number of obstacles that restrict their use of AI and IoT in agriculture, chiefly because of financial limitations, a lack of knowledge, and a lack of technical infrastructure and assistance.

High Initial Costs and Financial Barriers: Small and medium-sized farmers in Punjab frequently find the cost of AI and IoT technology, like sensors, drones, and precision farming software, to be prohibitive. Many farmers, who are already struggling financially due to the increased cost of basic inputs like fertilizers, see these technologies as extra, unaffordable costs. The situation is further made worse by the lack of readily available, reasonably priced loans, which prevents many farmers from obtaining the money they need to invest in cutting-edge technologies [23].

Awareness and Technical Knowledge: Farmers in Punjab, particularly in rural regions, are often unaware of the potential advantages of AI and IoT for their operations. Due to the fact that farmers are frequently ignorant of the technology or doubt its usefulness, there is a noticeable lack of training and instruction. They are still reluctant to invest since they do not understand how these instruments may maximize yield and lower input costs. Furthermore, farmers are unable to fully benefit from AI and IoT solutions since government programs that encourage modernization are underutilized due to a lack of technical assistance and outreach.

Adoption of IoT-based solutions, which need stable data transfer for real-time monitoring and analytics, is severely hampered by poor rural connectivity and erratic internet access. This is particularly difficult in the more isolated regions of Punjab, where internet infrastructure might not be strong enough to sustain constant data flows from IoT devices, hence restricting the efficient use of these technologies [24].

Many farmers are reluctant to embrace new technologies due to cultural preferences for conventional farming practices and a dearth of successful local examples. Since farmers sometimes rely on generational experience, switching to AI-driven techniques can appear dangerous in the absence of concrete proof of its advantages in their particular setting.

Punjab has a large number of tiny, dispersed farms, which can make it hard to use expensive, high-tech solutions. Adoption of AI and IoT, which are frequently more economical on larger, consolidated farms, may not yield enough returns for small-scale farmers.

CONCLUSION

In conclusion, poor soil quality, growing input costs, a lack of modernization, and farmer financial distress are serious obstacles to Punjab's agriculture. These issues have an effect on local farming methods, decreasing output and raising costs, especially for farmers who depend on chemical

fertilizers and crops that require a lot of water. By giving farmers access to real-time data on soil health, water consumption, and fertilizer requirements, the implementation of AI and IoT has the potential to revolutionize Punjab's agricultural landscape. This data-driven strategy can address challenges of soil degradation and promote sustainable practices in areas like Majha, Doaba, and Malwa by optimizing input utilization, cutting waste, and improving soil quality.

Punjab's agricultural crisis is a complex web of interrelated issues, where soil degradation, high fertilizer costs, water depletion, and debt cycles exacerbate one another. Excessive use of chemical fertilizers to boost yields has degraded soil health and increased production costs, pushing farmers toward high-interest loans from informal lenders when they cannot afford these rising inputs. At the same time, intensive irrigation practices have depleted water resources, creating further strain on farming in water-intensive regions. The financial burden from these escalating input costs, coupled with soil and water mismanagement, has trapped many farmers in a cycle of debt, leading to significant socio-economic distress.

AI and IoT-driven solutions have the potential to disrupt this cycle by providing farmers with precise, data-driven insights that optimize input usage and conserve resources. Real-time soil health data from IoT sensors can guide targeted fertilization, reducing dependency on chemical fertilizers and improving soil quality over time. AI-driven irrigation systems can help manage water more efficiently, particularly crucial in Punjab's regions facing water scarcity. Furthermore, AI-based financial tools could offer alternative credit solutions, helping farmer's access affordable loans and easing reliance on informal lenders. By integrating these technologies, Punjab's agricultural sector can move toward a more sustainable and economically viable model, addressing multiple issues simultaneously for long-term resilience and growth. Adoption of technology is hampered by issues including high prices, a lack of technical expertise, and poor infrastructure, which need to be solved. Policymakers, financial institutions, and agricultural specialists must work together to remove these obstacles by offering reasonably priced access, assistance, and training. Financial technologies driven by AI may also be essential in providing alternative loan options, lowering farmers' reliance on unofficial lenders, and easing the hardship brought on by debt.

A possible solution to address the interrelated problems of soil health, reduction in the use of fertilizers, economic viability, and financial resilience is through the integration of AI and IoT in Punjabi agriculture. This study highlights the necessity of technical inclusion and legislative assistance to guarantee that innovations benefit all farming communities in the area, fostering fair growth and long-term agricultural sustainability.

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