A Perspective on Application of Artificial Intelligence in sustainable Agriculture (With special reference to precision agriculture)

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Abstract

Agriculture has undergone rapid technological changes in the search for greater productivity. At the same time, changes in the environment and agricultural crises that appear from the possible repercussions of climate change and the different uses of land and technology make tools that look to minimize the negative aspects of the environment and human beings increasingly necessary. In this context, the concern with sustainability is imperative. Different agricultural systems have been trying to connect with this issue, making the term sustainable a field of conceptual, political, ideological, and power dispute. On this note, Artificial intelligence (AI) can be used as a tool to enhance the growth prospects of sustainable agriculture, therefore this paper attempts to analyze how AI could aid the sustainable agriculture keeping in mind about the accessibility challenges for the small and marginal farmers. Paper will also explore the prospects of agrometeorology and precision agriculture as a concept and how it would play an important role in smart harvesting, and finally the papers will also look to oversee the influence of AI in agroecology. The paper would also explore the common grounds between Indian and Brazilian agriculture especially the small and medium farmers scenario and their challenges in accessing this technology and how the government could aid the use of these technologies through inclusive policy interventions.

Keywords: *Agrometeorology, Sustainability, Efficiency, Artificial Intelligence, Agroecology*

Introduction

Agriculture has undergone rapid technological changes in the search for greater productivity and sustainability. The sector clearly requires the support of technological advancement to ensure clean, green, and effective agricultural practices. In this context, the concern with sustainability is imperative. Different agricultural systems have been trying to connect with this issue, making the term sustainable a field of conceptual, political, ideological, and power dispute. Here, sustainable agriculture will be understood as a process or even an ideal type of reference. In other words, agricultural processes that are consistent with the view of land use, concerned with the ability to support the economic, social, and ecological functions of agroecosystems, are suitable for this category, understanding the maintenance of biodiversity as a critical element. Given the diversity of ways of life, agricultural practices, environment, history, potentials, and weaknesses, it is assumed that there may be variations in these processes. In other words, agricultural processes that are consistent with the view of land use, concerned with the ability to support the economic, social, and ecological functions of agroecosystems, are suitable for this category, understanding the maintenance of biodiversity as a critical element. Given the diversity of ways of life, agricultural practices, environment, history, potentials, and weaknesses, it is assumed that there may be variations in these processes.

Artificial Intelligence (AI) is currently in the context of technological transformations in agriculture. In the simplest terms, AI which stands for artificial intelligence refers to systems or machines that mimic human intelligence to perform tasks and can iteratively improve themselves based on the information they collect. AI is much more about the process and the capability for superpowered thinking and data analysis than it is about any format or function. Although AI brings up images of high-functioning, human-like robots taking over the world, AI isn't intended to replace humans. It's intended to significantly enhance human capabilities and contributions. That makes it a very valuable business asset.

There are different ways to think about and practice agriculture. One example of this is the difference between the agriculture of agroecological bases and conventional agriculture. So, technologies and AI cannot apply to all places in the same way. It demands a look at their adaptations to local conditions. Thinking about the concept of sustainable agriculture delineated, AI can be used for: pest detection; soil and crop health monitoring; smart irrigation management; increase in production; and Agrometeorology smart harvesting.

With the advent of information technology, innovation associated with computer data has been highlighted as an essential ally for increasing agricultural productivity without losing sight of the parameters necessary for a trajectory of sustainability. Precision agriculture is a production management system that supplies background to connect production platforms to information technologies and Artificial Intelligence. The association of these elements makes it possible to generate a large amount of data for monitoring production conditions (soil, culture, climate, water...). Agrometeorology is also included here, with its decision-making support systems based on models, which introduces the climate factor in data management.

All these aspects are highlighted as positive, but for the producer to be engaged, there must be sources, training, and service providers that support them. There is a technical dimension associated with the process and a socioeconomic and cultural dimension (including how farmers mobilize, think, and practice agriculture in different locations on the planet). A challenge in this technological field is how to integrate the social aspects present in rural, for example, India and Brazil, with a diversity of producers, economic conditions, biomes, cultures, and climate.

So, it is vital to think about not only the perspective of the farmers but also the real condition of the use of this system. There are crucial factors like costs, physical infrastructure, distance, and knowledge, among other things, which can generate new elements of exclusion in the field and reproduction of power by digital tools. In addition, although it is not the focus of the present work, it is worth mentioning that there is still a gap about the rights to use data collected on farms by digital equipment suppliers. How will this information be used and stored? How will this data be protected? With the end of the contract with the technology company, what happens to the data collected? Many issues still permeate this production system and whose legislation has been studied.

With the above considerations in mind, our goals are:

Objectives

- To analyse the need for and importance of precision agriculture and agrometeorology in contemporary-day farming.

- To introduce a model for accessing the AI services.
- To suggest policy recommendations to the government.

Research Methodology

The study is based on a descriptive analysis where data are accessed from secondary resources, renowned journals, research papers, government reports, and newspaper articles. For better representation of data, various forms of charts and other analysis-friendly flow diagrams are used.

Importance of Precision Agriculture and Agrometeorology in Contemporary-Day Farming

The accelerating growth and innovation in science and technology, and its extended relevance in agriculture give us the scope to promote the practice of sustainable agriculture. The use of these technologies is no longer a want but a necessity to farmers as they face many Agri-oriented issues in recent times. It can also be assumed that the challenges that these farmers are going face are going to be bigger than what we could imagine. Some of the problems they could face can be mitigated and eradicated if they could predict the possibility of their occurrence. One of the most causal issues is plant pathogens and their associated diseases.

Plant pathogens and pests handle up to 40% of maize, potato, rice, soybean, and wheat crop yield losses worldwide (Savary et al., 2019). Plant diseases caused by bacteria, fungi, nematodes, and viruses cost the global economy USD220 billion annually (Savary et al., 2019). Viruses make up almost half of the plant disease-causing pathogens at an annual global cost of more than USD30 billion (Nicaise, 2014). Rice is cultivated in 100 countries, supports nearly half the world's population, and is at risk from multiple vector-transmitted viruses, costing USD1.5 billion annually. In 2019, the International Committee on Taxonomy of Viruses recognized 1484 plant viruses. Like animal viruses, plant viruses are grouped based on viral genomic structure. Therefore, this gives the importance of detecting, tracing, and treating these issues before they become a global food security concern.

Faced with the challenges, agriculture is one of the many sectors that can receive help from digital transformation, using information and communication technologies aimed at their problems. Among the technologies/tools related in this scenario are Big Data and Data Science, Artificial Intelligence (AI), Virtual Reality, Robotics, and Machine Learning.

According to Kar, Kumari & Singh (2022), AI is a tool that allows machines to solve problems, learn and integrate various human functions, such as perception, memory, language, or planning. Using data sets, facts, and knowledge to make predictions, AI can help preserve the environment by identifying factors such as emissions and energy reductions, CO2 reduction, deforestation, climate change, plant disease, and accident prediction, among other aspects of sustainability in agriculture. Mentioning the work of Hill (2018), one of the examples brought by the authors as an area of application of AI is in the management, treatment, transport, and recycling of water. AI and "machine learning" tools can effectively treat and detect harmful particles in water. Moreover, algorithms and approaches used for wastewater treatment can continually adapt to new information. It is noteworthy that one of the problems is the need for specialists to interpret data. In addition, algorithms have been created to monitor soil quality and crop health, make predictions, and analyze climate variability for crop growth, working with other tools such as drone images.

Transformations in Agriculture and The Recent Demands

Since the beginning of the 20th century, agriculture has been going through increasingly rapid stages of technological transformation. At the beginning of the century, the main character was the use of hand tools and animal traction. Over time, advances were made in mechanization and developing fertilization, planting, and harvesting techniques. After the middle of the century, more specifically in the post-war period, the use of chemical products in crops was associated with new technologies. It is only recently that the precision agriculture was inaugurated, with the evolution of machines, computational support, and improvement of implements to increase the efficiency of agricultural activity.

It should be noted that this increase in efficiency does not necessarily mean sustainability. It is worth noting the advance of monoculture and the loss of biodiversity in many of the globe. In any case, precision agriculture, through machines and sensors, uses satellite images, for example, which has allowed the consolidation of a database with relevant information from the field.

The demand for sustainability, however, has launched challenges in this area when they point to the need for technological aspects that consolidate production systems friendly to the environment. There are advances in the areas of ecologically based agriculture. Systems are becoming more complex, and the environment is launching new challenges. These new challenges introduce digital technologies to the context of precision agriculture, with the development of tools that consider the social, biological, environmental, and economic aspects of using technologies. Therefore, it is associated with the context of precision agriculture, digital agriculture, using data mining technologies, high-performance computing, modeling and simulation, computational algorithms, supercomputers, analysis and modeling tools, and information networks at different levels of complexity (Massruhá *et al.*, 2020).

In short, according to the international society of precision agriculture, "Precision Agriculture is a management strategy that gathers, processes and analyses temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production."

Precision Agriculture relies upon specialized equipment, software, and IT services. It includes accessing real-time data about the conditions of the crops, soil, and ambient air, along with other relevant information such as hyperlocal weather predictions, labour costs, and equipment availability. The real-time data is collected via sensors in fields that measure the moisture content and temperature of the soil and surrounding air. Satellites and robotic drones can also provide farmers with real-time images of individual plants. The technology leveraged in this process helps efficiently use land, water, fuel, fertilizer, and organics inputs; searching will ensure sustainability by reducing cost and environmental impact. Examples of these technologies are shown in the box below.

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Box 1. Technologies used in precision agriculture

Technology	Uses	Benefits to farmers
Drones	**Agricultural mapping and field scouting.**	**Effective Application of fertilizer and pesticides.**
Mobile applications	Soil sampling and analysis	Instant information about soil health.
GPS /Satellite	Access to Geospatial data and effective management of resources.	Helps in planning the irrigation and use other organic chemicals
Farm automation and robots	Faster reaping of the crops	Eases the work of farmers
Internet of things	Sensor and voice recognition access	To faster and hazel free implementation.

It is important to note that artificial intelligence tools are used in the field and other links in the agricultural production chain, with potential benefits for all, according to figure 1. Considering this larger scope of agricultural production chain, examples of digital technologies that can be used in the agricultural production chain: are applications and software; cloud computing; machine learning, remote, and proximal sensors; automation and robotics, 3D printing; digital platforms; information systems; big data; artificial intelligence; social networks; GPS Systems, Blockchain and Encryption, Internet of Things, Satellites, Nanosatellites and Vans, Telemetry.

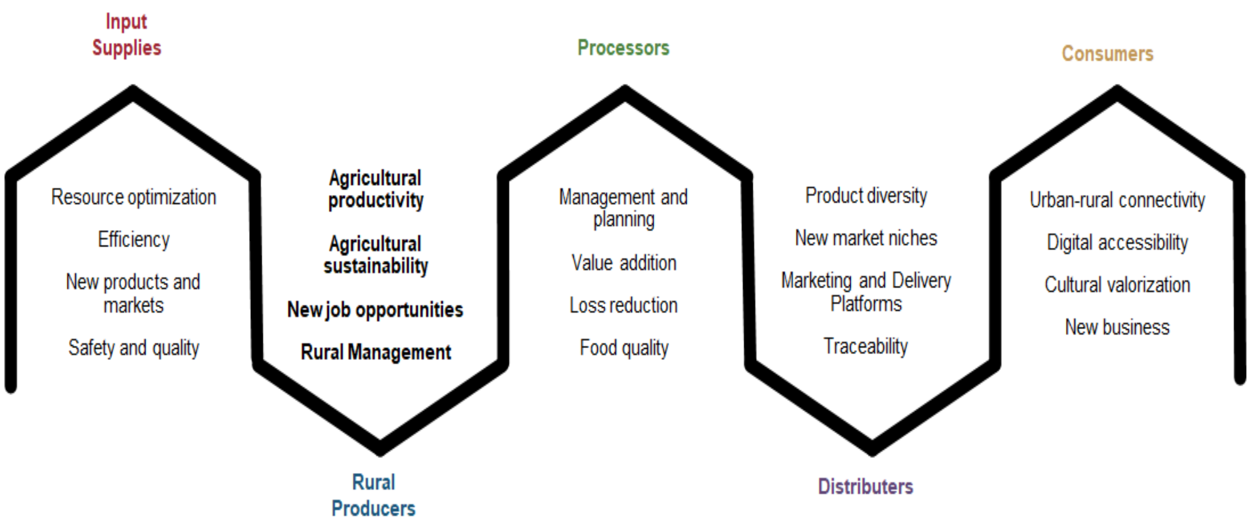

Fig. 1. Potential benefits of digital transformation in the agricultural production chain
Source: based on Bolfe et al., (2020)

Scenario for Agriculture Transformation in Northeast of Brazil

The Brazilian Northeast region is characterized by a relatively lower-income rural population and the family farmer (FF) predominance, mainly focused on the local food diet. 59% of the extremely poor in Brazil are concentrated in this region (IBGE, 2011). The FF consists of small farms, with the predominant use of family labor and family income originating predominantly from the rural area. The Northeast (NE) concentrates almost 60% of the FF of the country (Teixeira, 2019).

Furthermore, the NE covers 18.27% of the Brazilian territory, with 1,561,177.8 km², of which 1,007,438 km² cover the semiarid region, that is, 64.53% (Fortineti, 2020). This region is characterized by irregular

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rain distribution in the year, with low annual precipitation (less than 800 mm) and high temperatures. The Caatinga is the seasonally dry forest exclusive of the Brazilian Semiarid.

More than 1 million and 260 thousand km2 in 1,440 municipalities in 8 states in the Northeast and northern Minas Gerais state (in the southeast) are susceptible to desertification. In 10 years, deforestation in the Caatinga has reached an area equivalent to Portugal (almost 50% of its extension is susceptible to desertification)[1].

In these regions, vegetation no longer responds to rain, so the problem goes beyond the prolonged drought. Agroecology and its ecological principles associated with agricultural practice then become a necessity. Conventional agriculture, with deforestation practices, burning and using poison and chemical fertilizers, increase the environmental damage making the production more expensive and challenging to maintain small production. The population depends on agriculture to survive and complement its yield.

The impacts of climate change tend to alter crop standards. Thus, evaluating the relationship between vegetation, crops, water, soil, and environmental drivers is necessary. From this information, it is possible to identify the dominant forces in the environment that trigger challenges that must be overcome. In this way, AI can be an essential tool.

In partnership with other institutions, the Embrapa (Brazilian Agricultural Research Corporation)[2], a public corporation, developed in 2018 two technologies. The AGLIBS 1.0, an AI tool for soil mapping, soil carbon analysis (C), texture (sand, silt, and clay contents), and pH; and the SpecSolo®, for soil analysis by near-infrared spectroscopy that uses Big Data and Artificial Intelligence techniques, developed with a database with more than 1 million soil samples of Brazil. The question is, does this type of technology reach the small producers?

Agrometeorology

The growing unstable weather pattern in the world makes harvesting a difficult task for farmers, especially those with limited land access and other natural resources like water. The 21st-century technological development surprised us with its growing trend in scientific inventions, and in the years to come, these trends will surprise us beyond our expectations. The unpredictable climate on one side and accelerating scientific development on the other side give us the scope to identify the optimum use of science in this context. This demand for an intervention using AI to determine the weather pattern and suggest modification in harvesting can be called agrometeorology. Agrometeorology helps us to detect, treat and mitigate externalities in agriculture, where the study is very much essential given the growing climatic and other plant-oriented diseases.

Michel frere[3] a senior agrometrologist from Harvard defined agrometeorology as a "science which aims at applying meteorological knowledge to the improvement of agriculture". According to the author "*this can be done in two ways: Firstly, by creating the best conditions to enable the crops to utilize as well as possible the climatic factors with are favorable to the production of organic matter, secondly, by looking for ways to avoid or to reduce the direct or indirect adverse effects of metrological phenomena which are*

[1] Available at: https://www.embrapa.br/busca-de-noticias/-/noticia/3240771/desertificacao-atinge-grandes-areas-do-semiárido. Access: 02/06/2015.
[2] Available at: https://www.embrapa.br/. Access: 02/06/2015.
[3] Available at: https://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?bibcode=1979ESASP1020....3F&db_key=AST&page_ind=0&data_type=GIF&type=SCREEN_VIEW&classic=YES. Access: 10/11/2022.

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harmful to crops, such as droughts, frosts, hail. This also includes the fight against crop diseases, the evolution of which is often influenced by weather conditions."

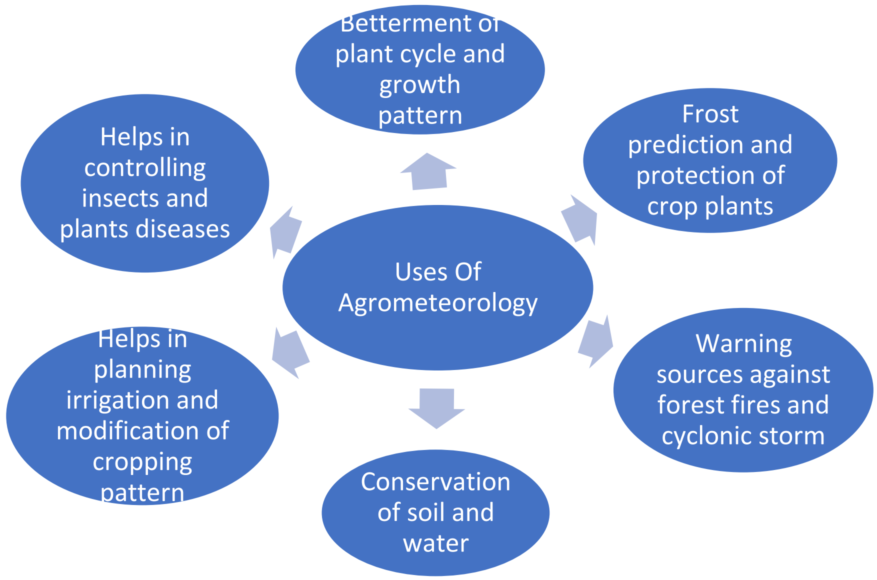

Fig. 2. Uses of agrometeorology

Present Agrometeorology Initiatives in India and Brazil

Brazil

The Caramori and Oliveira survey[4] indicated the existence of seven agrometeorology centers supported by the state governments, one by the federal government, and two cooperatives of farmers that operate networks of meteorological stations. The government centers are in São Paulo (SE), with the Campinas Agronomic Institute and its Integrated Information Center for Agriculture, and a network of mechanical and automated weather stations, providing water balance and maps of agrometeorological variables. In the South region, the Agronomic Institute (IAPAR) and the Meteorological System, both in Paraná; the Agricultural Research Corporation (EPAGRI) in Santa Catarina; and the State Agricultural Research Foundation of Rio Grande do Sul also manage networks of mechanical stations and automated stations, with daily/weekly updates and forecasts available on their websites. In Goiás (CO), the Meteorological System operates a network of automated stations with satellite transmission and data display on its home page. For Ceará (CE), the State Meteorological Foundation has a network of automated rainfall stations supporting regional irrigation and subsistence agriculture projects, especially in severe drought. The National Institute of Meteorology has a network of mechanical stations distributed throughout the country, providing daily forecasts on weather conditions, thematic maps of temperature, precipitation, evapotranspiration, and water balance, among others. The National Institute for Space Research (INPE) maintains a network of automated stations with data published on its website.

Many other research institutions and companies try to obtain meteorological information to help with production conditions in agriculture. But these experiences are dispersed and sometimes not organized to find small properties in different regions, biomes, and climates. Like India, Brazil has a continental dimension. Many farmers who are in remote areas do not have adequate access to the internet or do not

[4] Available at: http://www.agrometeorology.org/files-folder/repository/brasile.pdf. Access: 10/11/2022.

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know how to handle this information. It demands more significant support from governmental research institutions.

A concern that must be kept in mind is the power relations that can be established by using artificial intelligence and the gaps that can be generated between the various publics of the agricultural sector. The importance of artificial intelligence is not questioned here. Still, there is a concern about democratizing access to data so that the positive impacts of using new technologies can be leveraged, seeking to minimize asymmetries.

From a technical point of view, there are the so-called agriculture 4.0 and now agriculture 5.0, to which various data technologies are related, including the 5G internet. In possession of the Brazilian reality, large landowners responsible for the so-called agribusiness, focused mainly on commodities for export, can more easily benefit from these innovations, with greater access to data technologies developed by start-ups, for example. The question is: how can family farmers located in areas of the Brazilian semiarid region, with difficult access to the internet, have a lower level of knowledge of the tools and with a governmental structure of rural extension weakened by the reduction of resources destined to them in recent years, can benefit from these advances?

Another issue that should be highlighted is that the mix of data technologies involved also raises concerns about the disappearance of humans' role in using artificial intelligence as if humans were becoming obsolete (Bronson, 2022). We point out in this article that we may be facing different contexts of applicability of artificial intelligence, whether within agrometeorology or not. In family farming, artificial intelligence applied to agrometeorology arrives as a complement/help in the rational use of scarce resources, especially considering the need for water management in the semiarid region.

India

In India, evidence of agrometeorology can be traced back to 1945 when the weather conditions were addressed on the radio to the farmers making the accessibility to the information included. As we get modern, where technological influence takes place, the accessibility cost to such information becomes higher. At present, the government has made efforts to establish District agrometeorology advisory centers, but the efficiency in its operation is highly questionable. Keeping the benefits that agrometeorology could bring to the farmers in both countries, the government should implement policies enabling small and medium farmers to access the benefits.

Although at present, the ministry of earth science's initiative in collaboration with the Indian meteorological department and the state agricultural university, and the Indian council for agricultural research introduced a scheme called Gramin Krishi Mausam Sewa. It issues crop and location-specific weather-based agro advisories for the benefit of the farming community. The Agro-meteorological Advisory Services (AAS) under the GKMS is operated to prepare biweekly weather-based bulletins. The information is transmitted through multimedia channels and SMS to help farmers plan farm operations accordingly.

Apart from this initiative, institutional-level efforts have been taken to forecast the weather for the consumption of the farmers but there is no specific approach on a Pan India basis in this regard. The national mission for sustainable agriculture plans on these side-lines to implement the idea of precision agriculture and agrometeorology services. However, the benefits of the same could be visible in the years to come. The district agromet advisory services in India provide weather forecasting services for the farmers but they do not disseminate any AI-based data services where they can access data to plan irrigation etc.

Accessibility Constraints Faced by the Farmers

Taking Brazil and India into consideration, the countries have distinct weather patterns, crop preferences, and market accessibility, but they found common ground in accessibility to modern technologies in agriculture. In both countries, large farmers access technological benefits, making agricultural infra development non-inclusive. The efficient way to make this infrastructure accessible to small farmers is to strengthen the implementation strategy of the government. The main challenge is to mobilize resources, strengthen institutions and create innovative mechanisms for implementing policies. This model of AAUI helps the three-tier system of government to plan and executive the model, which will enable the farmers to access the AI services present constraints.

The constraints that the famers undergo in accessing are the cost of the infrastructure, as we know that most of the farmers in India and in Brazil are small and medium farmers who majorly do not get access to basic support like finance and other essentials to practice agriculture. This is where the government should play a role as a facilitator in accessing the infrastructure.

Agromet Artificial Intelligence Units (AAIUs)

India and Brazil are countries with a strong policy planning strategy but with a weak execution strategy. This model of AAUI helps the three-tier system of government to plan and executive the model, which will enable the farmers to access the AI services. As mentioned in the earlier discussion on accessibility, the intervention of government with the cooperative governance can be effectively used to address the issue of non-inclusiveness in accessing this infrastructure. Therefore, in order to make the infrastructure accessible to all farmers irrespective of their land holdings, the government should own the infrastructure and provide the access through hub and spoke model. Where satellite hubs are created, which collects the data and spokes which are regional centers that provides the information(data) and the infrastructure for the consumption of the farmers. The work process of the model is explained later in the paper. The model is introduced in the country either as a central sector scheme or as a centrally sponsored scheme.

Blend of Top Down and Bottom-Up Approach

The scheme is assumed to be a blend of top down and bottom-up approach, the model assumes to have an ideal political scenario and cooperative governance between the central and regional government. The model assumes to have bottom-up approach in terms of planning and top-down approach in terms of execution. The bottom-up approach is planned from the grass root level knowing the need from the farmers point of view followed by the specialist and technicist opinion for the framing the policy.

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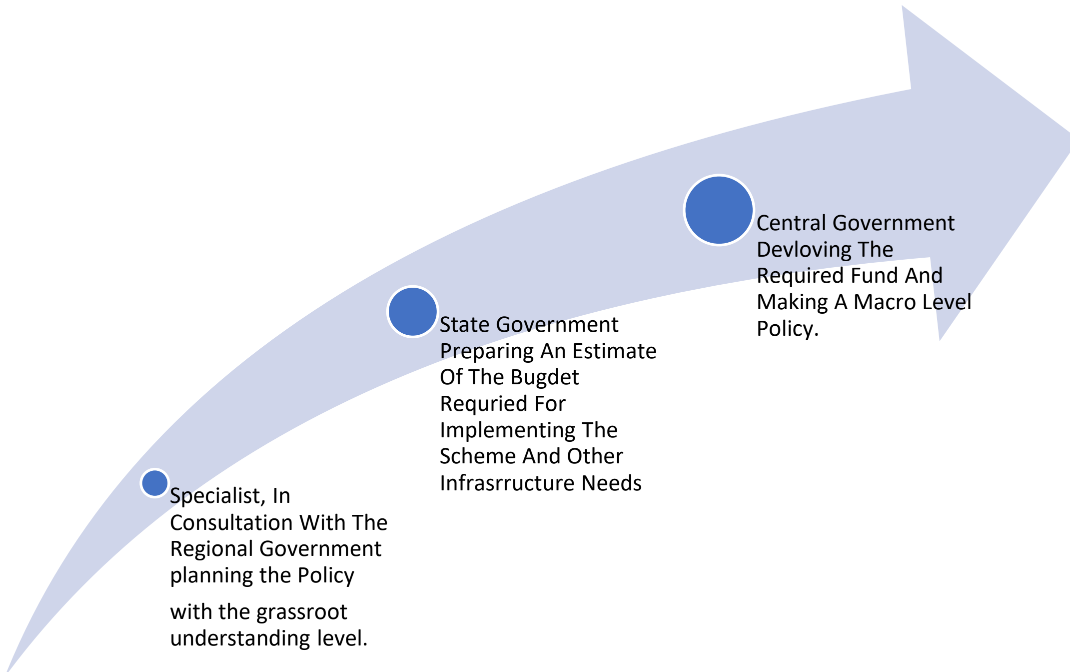

Fig 3 Bottom-Up Approach on Planning

The plan of the policy commences with a specialist body with the consultation of the regional government, understanding the grassroot level need of the infrastructure prepares a report and submits to the state government. The state government who has a better understanding of the region will prepare a budget which is required to implement the scheme and to install the infrastructure. The central government checks the requirement and then prepares a PAN India scheme for the farmers. The main purpose of the bottom-up approach helps us to identify the grass root level requirement and make the policy Tailor made for the regional beneficiaries. If the region does not require certain infrastructure as its crops have a counterproductive natural advantage over the infrastructure, then the intended infrastructure may not be required in that region. This overlapping or unwanted installation of technologies can be avoided through his approach.

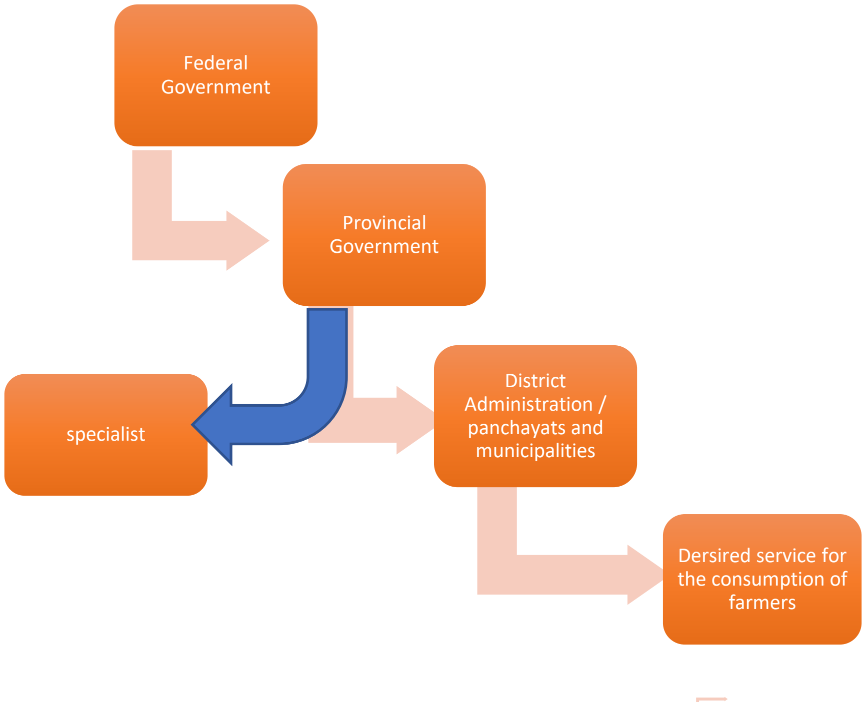

Fig-4 Top-Down Approach of Execution

After the planning of the scheme the central government devolves the fund to the respective state government and the features of accessing the infrastructure of the scheme. The state government will devolve the funds and responsibility to implement to the regional authority. The state government will outsource a technical specialist who will help with the operational and maintenance of the infrastructure in the respective region.

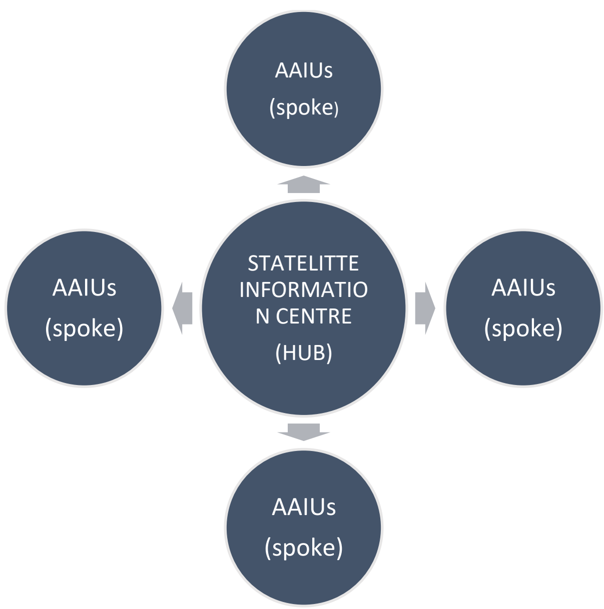

Fig 5 hub and spoke model

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Hubs	Spokes
Created and located strategically with in the region under surveillance of the district administration.	Created and deployed strategically with in the region under the surveillance of the municipal government.
Collects information from the Satellite and transfers the data to the spokes with region specificity	Collects and interprets the data from the hub and simplify it for the consumption of the farmers.
Handled by the specialist private player who the state government have outsourced the services to.	Handled by the scientist or the private player to whom the services are outsourced.
	Will have all the AI technologies required for the sustainable agricultural practices.
	Will capacitate the farmers with the necessary help to practice and access the infrastructure

The spokes are the **Agromet artificial intelligence units AAIUs**, which provide the information that is required for the farmers to practice sustainable agriculture. The AAIUs will also contain the required infrastructure such as access to drones and UAVs for the farmers consumption in that region. the farmers will use this infrastructure with the help of these mechanist in the unit. All the farmers irrespective of the land holding will have access to these infrastructure in the region for their respective farm use. The units will also predict the weather with the help of data received from the hub through satellite instantly and provide that information to farmers in the region to plan their irrigation strategically there by reducing the water consumption for irrigation. This method can also be followed for the fertilizers and other organic chemical required to use. The spoke will also provide information that is required to use the AI in the region for the agricultural practices. This will certainly help the farmers in detecting, tracing, and preventing non unstainable agricultural practices.

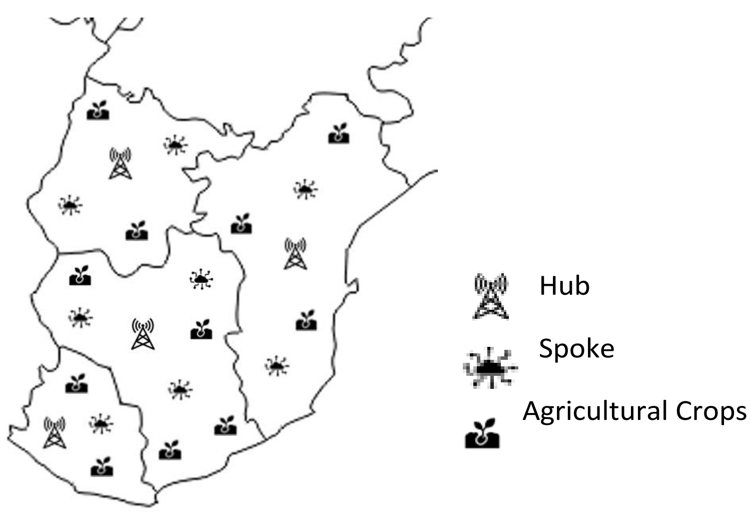

Fig 6 location of the hub and spoke post introduction of the scheme

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