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Research Article

HARNESSING TECHNOLOGY: PLASTICULTURE THROUGH REMOTE SENSING, GPS AND GIS FOR SUSTAINABLE SOIL AND WATER MANAGEMENT

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Abstract

The integration of advanced technologies such as Remote Sensing (RS), Global Positioning Systems (GPS), and Geographic Information Systems (GIS) with Plasticulture has emerged as a transformative approach to sustainable soil and water management in agriculture. As global food production must increase by 70% by 2050 to meet the needs of a growing population, traditional farming methods have led to soil degradation, water scarcity, and declining yields. Precision farming, leveraging Plasticulture, addresses these challenges by optimizing resource use and enhancing productivity. Plasticulture involves the use of plastic materials such as mulch, drip irrigation systems, and plastic-covered greenhouses which play a critical role in conserving water, controlling weeds, and regulating soil temperature. Notably, Plasticulture can improve crop production by 50-60% and reduce water usage by up to 70%. The integration of RS, GPS, and GIS technologies further enhances the potential of Plasticulture by providing real-time monitoring of soil health, moisture levels, and crop conditions. Remote Sensing offers valuable insights for early detection of crop stress, while GPS ensures accurate application of inputs and resources, and GIS enables detailed spatial analysis for informed decision-making. These technologies enable farmers to adopt precision agriculture practices, reducing input costs by up to 15% and improving crop yields by 20%. While Plasticulture and advanced technologies offer numerous benefits, challenges remain, including the environmental impact of plastic waste and barriers to adoption, such as high initial costs and limited access to infrastructure in rural areas. Proper management of agricultural plastic waste, including recycling initiatives and policies, is crucial to mitigate the environmental risks associated with plastic use in agriculture. In conclusion, the synergy of Plasticulture with RS, GPS, and GIS presents a sustainable path forward for agricultural practices, enabling efficient resource use, enhancing productivity, and promoting environmental conservation. Collaborative efforts among government agencies, research institutions, and farmers are essential to fully harness the potential of these technologies for sustainable agriculture and long-term food security.

Keywords: Plasticulture, Remote Sensing (RS), GPS, GIS, Precision Agriculture, Sustainable Soil and Water Management, Agricultural Waste, Resource Optimization, Crop Yield, Plastic Waste Management

INTRODUCTION

In a world increasingly burdened by population growth, climate change, and resource depletion, the agriculture sector faces the daunting task of producing enough food sustainably. According to the Food and Agriculture Organization (FAO), global food production must increase by 70% by 2050 to meet the needs of an estimated 9.7 billion people. However, conventional agricultural practices lead to soil degradation, water scarcity, and reduced crop yields. In India, for instance, over 30% of the country's agricultural land is classified as degraded. Today, some important issues for agriculture are

- Low productivity – ever increasing population, resource poor farmers.
- Improper use of natural resources.
- Uncertain and varying climatic conditions (Spatial as well as temporal)
- Climate change
- Needed diversification hindered due to climate and other natural resources and Socioeconomics

Sustainable soil and water management emerges as a cornerstone for addressing these challenges, ensuring food security while preserving natural resources. The advent of technologies has revolutionized high-tech agriculture combining traditional practices with modern technology. The world is moving towards third modern farming revolution in the form of Precision Farming.

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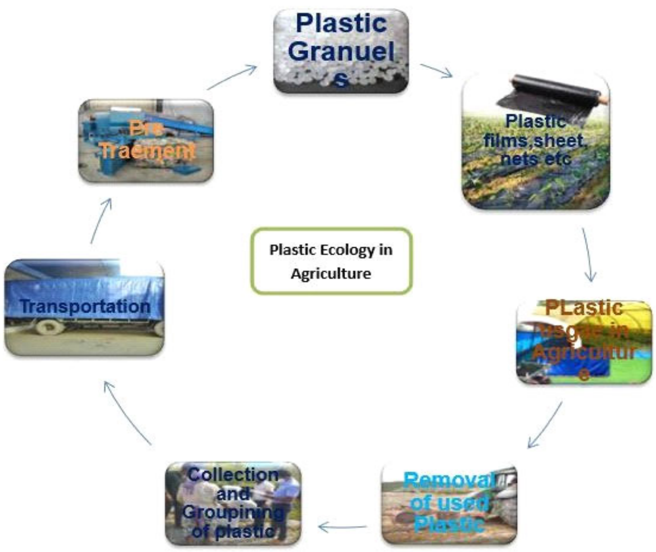
Precision Agriculture synonym to Smart Agriculture, is a technology-enabled approach to farming. According to a 2021 report by Markets and Markets, the global precision farming market is projected to grow from $7.0 billion in 2020 to $12.9 billion by 2025, at a CAGR of 12.2%. In order to meet the increasing food demand various Precision farming technologies are used**.** Plasticulture Technology play a significant role in precision farming. Plasticulture technique of farming developed in the mid of 20th century is gaining popularity among the farmers globally, revolutionizing the way modern agriculture is practiced. Plasticulture combines use of plastic in agriculture i.e. synthetic polymers in agriculture particularly for soil and water management.



Plasticulture technique involves plastic Mulch, in this plastic helps retain soil moisture, control weeds, and regulate soil temperature, in Drip Irrigation systems where plastic pipes and emitters deliver water directly to the plant roots, and Plastic-covered greenhouse structures provide controlled environments for crop production contributing to sustainable practices.

According to the FAO, some 12.5 million tonnes of plastic products was used in the agricultural value chain in 2019. Global Plastic product market will grow from $1142.21 billion in 2024 to $1512.15 billion in 2028 at a compound annual growth rate (CAGR) of 7.3%. (https://www.researchandmarkets.com/ report/plastic-product)

India is the third largest user of plastic after America and China. Indian Plastics Market was worth US$ 43.68 billion in 2023 and total revenue is expected to grow at a rate of 6.6% CAGR from 2024 to 2030, reaching almost US $ 68.33 billion in 2030. India has increasingly adopted Plasticulture and to promote plasticulture i.e. application of plastics in agriculture, the National Committee on Plasticulture Applications in Horticulture was started in 2001. This subsequently renamed to National Committee on Precision Agriculture & Horticulture.

In Plasticulture, "Agri Plastic" products are made of polymers such as Low-Density Polyethylene (LPDE), Linear Low-Density Polyethylene (LLDPE), Polypropylene (PP) and Polyvinyl Chloride (PVC). Agri-plastics play a crucial role in enhancing agricultural productivity by effectively managing important factors for crops and livestock, including temperature, light, humidity, irrigation, weed and pest control, and crop and fodder protection. This also leads to a reduction in the consumption of resources such as water and chemicals. Agri plastic products include films to cover greenhouses and tunnels, mulch to cover soil, shade cloth, pesticide containers, seedling trays, protective mesh and irrigation tubing. It helped the farmers across the globe to manage inputs that ensure the optimum needs of crops and soil, besides enhanced disease free and healthy produce with better remunerative value.

The following are the main areas where Plasticulture technology is used:

Benefits of Plasticulture are

Increased Yield : Mulching films and greenhouses create a favorable microclimate, extending the growing season and increasing yields of agricultural crops.

Crop Protection: Plastics protect crops from weather, pests and diseases, reducing losses and improving crop quality.

Efficient Water Management: Plastic irrigation systems allow for precise water distribution, optimizing consumption and improving water resource efficiency.

With the help of using Plasticulture for agriculture many notable improvements have been evidenced such as

Parameters	Percentage
Improvement in Production	50% - 60%
Saving of Water usage	60%-70%
Saving of Fertilizers	30%-40%
Savings on Labor	7%-18%
Early fruiting, Excellent quality of seedlings & Enhances quality of produce	10-25 days

India is increasingly adopted plasticulture, especially in regions like Punjab and Haryana, where plastic mulching is used to improve soil moisture retention and control weeds. Plasticulture when combined with advanced technologies such as remote sensing, GPS, and GIS, offers a powerful approach to sustainable soil and water management. The integration of advanced technologies such as Remote Sensing and Geographic Information Systems (GIS) offers unprecedented opportunities for high-tech agriculture. Recent studies indicate that precision agriculture, driven by Remote Sensing and GIS, can increase crop yields by up to 15-20% while reducing input costs by 10-15%.

- **Remote Sensing (RS)**: Remote sensing involves acquiring information about the Earth's surface using satellite or aerial imagery. In the context of plasticulture, remote sensing can monitor crop health, soil moisture levels, and the effectiveness of plastic covers. By analyzing spectral data, farmers can detect stress in crops early and make informed decisions regarding irrigation and nutrient management. Valuable insights into soil health, crop conditions, and water resources are provided by this technology. Remote Sensing and GIS technologies help create detailed soil maps, indicating soil types, nutrient levels, and moisture content. Helps in monitoring water bodies, groundwater levels, and irrigation systems to optimize water use along with analyzing climate data to develop strategies for mitigating the impacts of climate change on agriculture.
- **GPS (Global Positioning System)**: Accurate positioning and mapping of agricultural fields are made possible by GPS technology. By using GPS, farmers can apply plastic materials with accuracy, optimizing their use and minimizing waste. This technology also facilitates the monitoring of land use and changes in agricultural practices over time, enabling better resource management. In the same way, GPS technology, combined with satellite imagery, allows for precise mapping and monitoring of agricultural fields, assessing crop health and detecting crop stress factors early, along with water management by Identifying areas with water logging or drought stress. Machinery using GPS, adjusts input application e.g., fertilizers or pesticides based on specific field conditions enabling optimization of resource use. Harvester enabled with GPS are capable to create yield maps, allowing farmers to identify productivity variations across their fields.
- **GIS (Geographic Information Systems):** GIS integrates various data layers to analyze spatial relationships. In plasticulture, GIS can be used to create detailed maps of soil types, moisture levels, and crop conditions. This information helps farmers make strategic decisions regarding irrigation practices, crop rotation, and the application of plastic materials, ensuring that they are used efficiently and sustainably. It integrates various data types to create detailed maps and models, aiding in decision-making processes. Similarly, GIS helps analyze soil variability, plan irrigation, and tailor treatments to specific

areas within a field. Drones- the Unmanned Aerial Vehicles are cost-effective and flexible tools for precision agriculture as they equipped with cameras capture high-resolution images for detailed field analysis. A GIS is an excellent computer tool for landscape modeling and analysis, able to capture, store, retrieve, manage and display huge amounts of spatial data.

By integrating plasticulture with Remote Sensing, Global Positioning System (GPS) and GIS, farmers around the world have optimized water use and soil management. Known for its advanced irrigation technology, Israel uses drip irrigation systems extensively, improving water use efficiency and reducing wastage. In Israel, government and private sectors collaborate to provide training in precision agriculture techniques. In the US, farmers are utilizing satellite imagery and drones for crop monitoring, leading to better resource management and increased yields and farmers also use GPS-guided tractors to minimize overlap in planting and reduce waste. In Germany, smart sensors and IoT devices help farmers make data-driven decisions based on live feedback from their fields. Netherlands employs high-tech greenhouses combined with climate control systems, optimizing water and nutrient usage while minimizing environmental impact. In Australia, Integrated Pest Management practices integrated with remote sensing technologies have significantly reduced pesticide use. Further by implementing satellite imaging along with utilizing drones equipped with sensors to gather detailed information to monitor crop health, soil moisture, and nutrient levels about crops and soil conditions, can inform timely interventions. Like, in Canada, remote sensing technologies are used to predict crop yields and monitor environmental changes and similarly in Brazil, drones are used for crop surveillance and to assess the efficacy of plastic mulching.

Regions in Europe, America, and Asia have widely adopted plasticulture practices, including greenhouse covers, mulches, and low tunnels. European countries have embraced Plasticulture for crop protection and yield optimization. To harness the full potential of Plasticulture in conjunction with remote sensing, GPS, and GIS, farmers around the world have been using this technology to support sustainable agriculture practices. Sustainable Agriculture Practices aims to address the issue of water scarcity and dwindling groundwater reserves. It involves working with and engaging farmers and implementing sustainable agriculture approach like Sustainable Soil and Water Management (SSWM) at the farm level. SSWM aims to optimize the use of soil and water resources while minimizing negative environmental impacts involving practices that maintain or enhance the quality and productivity of soil and water resources. Effective SSWM practices enhance soil health, promote biodiversity, and improve water use efficiency. Sustainable Soil and Water Management are essential for:

Key strategies for Sustainable soil and Water management include:

- **Soil Conservation Techniques**: Employing methods like contour farming, terracing, and cover cropping helps maintain soil structure and prevent erosion.
- **Water Management**: Rainwater harvesting, drip irrigation, and efficient irrigation scheduling can significantly reduce water usage while ensuring adequate supply for crops.
- **Nutrient Management**: Using organic fertilizers and crop rotation can enhance soil fertility and reduce reliance on chemical inputs.

The Indian government recognizes the importance of SSWM and the role of technology in agriculture.

In an innovative initiative government of India in its annual budget 2023-24 introduced a scheme with the purpose to focus on the Restoration, Awareness, Nourishment, and Amelioration of Mother Earth, The PM – PRANAM scheme. Various other schemes and programs are also in place to complement these initiatives:

Pradhan Mantri Krishi Sinchai Yojana (PMKSY): This program aims to improve irrigation efficiency through advanced technologies and promotes the use of drip and sprinkler irrigation.

Soil Health Card Scheme: Launched to provide farmers with information on soil health and nutrient management, encouraging sustainable practices. So far, more than 140 million Soil Health Cards have been handed out, promoting the balanced application of fertilizers.

National Mission for Sustainable Agriculture (NMSA): Focuses on enhancing productivity through sustainable practices, including the use of technology in agriculture.
Part of the Digital India Initiative, the DILRMP (Digital India Land Records Modernization Programme) promotes the use of digital technology in agriculture. Additionally, the initiative involves integrating GIS and remote sensing to enhance decision-making processes.

Integrating Sustainable SSWM with RS, GPS and GIS in Plasticulture can significantly enhance agricultural efficiency and sustainability. This combination allows for data-driven decision- making, optimized resource use, and better environmental stewardship. Despite the evident benefits, several challenges limit the adoption of sustainable practices and advanced technologies in Indian agriculture:

- **Lack of Awareness**: Many farmers are unaware of the benefits and subsidies of SSWM, RS, and GIS technologies.
- **High Initial Costs**: The upfront investment for advanced technologies can be prohibitive, especially for smallholder farmers.
- **Infrastructure Deficiencies**: Limited access to internet and technology hampers the implementation of precision agriculture practices.
- **Data Management Issues**: The effective use of RS and GIS requires accurate data, which may not always be available.

While Plasticulture has been endorsed as a way for farmers to efficiently grow crops along with managing water resources and cost saving on fertilizers and pesticides, it has also been called into questioned, as the agricultural practices generate huge quantities of after use plastic materials which constitute a waste that will need an appropriate collection and disposal. Farm plastic, if not stored and disposed of properly, can quickly contaminate the environment, seeping into rivers and posing a risk to soil health, which ultimately endangers livestock. Plastic waste is often incinerated in open areas, abandoned in fields or near waterways, buried underground, or dumped in landfills once they are no longer useful. Degradation of agricultural plastic materials, occurs because of exposure to solar radiation, rain, wind, extreme weather conditions such as temperature and humidity, and ultimately, exposure to chemicals, soil, stones, etc. Such inappropriate disposal of agriculture waste causes the accumulation of microplastics in the soil in turn affecting soil health, water contamination, releasing of harmful substances and air pollutants, food contamination, as well as also aesthetic pollution and landscape and the agro-ecosystem degradation (Briassoulis *et al.,* 2013). Improper collection and valorization schemes for agricultural plastic waste might lead to serious environmental problems in the long-term.

The majority of current mechanisms, policies, and laws concerning plastic do not specifically deal with agricultural plastics, as they mainly concentrate on other types of plastics. These policies, are limited to address specific aspects of agricultural plastic lifecycle, complexity, and broadness of applications, as well as difficulties associated with high contamination, low volumes, decentralized collection schemes, etc. Without proper systems for collecting and managing plastic waste, it could be left abandoned in fields, either buried or simply thrown away. Inadequate methods for managing plastic waste in agriculture can lead to the desertion and buildup of plastic remnants, which will break down into smaller particles (microplastics) when combined with plastic additives, will accumulate in the soil., specifically organisms such as earthworms, mycorrhizal fungi, and the overall soil microbiome, thus affecting soil health and productivity.

To address these challenges, a multi-faceted and Innovative approach is needed:

Awareness Programs: Government and NGOs should conduct workshops and training sessions to educate farmers about sustainable practices and technologies.

- Subsidies and Financial Support: Providing financial incentives for adopting modern technologies can encourage farmers to invest in RS and GIS systems.
- Strengthening Infrastructure: Improving internet connectivity in rural areas will facilitate better access to technology.
- Collaboration with Research Institutions: Engaging with agricultural research organizations can help in developing localized solutions based on data collected through RS and GIS
- IoT Integration: Combining Internet of Things (IoT) devices with RS and GIS for real-time monitoring and decision-making.
- Blockchain Technology: Using blockchain for transparent and secure transactions in the agricultural supply chain.
- Artificial Intelligence (AI): Leveraging AI for predictive analytics and precision farming.
- Database: The dedicated geo-referenced database, created for the present study in a GIS, permits to define the generation areas of plastic waste all over the territory and to identify the critical points of generation of APW. Further more this database increases the knowledge about the land, thus facilitating the implementation of action plans, helping decision makers and planners for selecting the best sites for disposal

Policy Recommendations

- **Incentivize Innovation**: Encouraging research and development in sustainable agricultural technologies.
- **Strengthen Extension Services**: Enhancing the capacity of extension services to disseminate knowledge and support farmers.
- **Promote Sustainable Practices**: In India, the Ministry of Environment, Forest and Climate Change, in 2016 introduced amendments to the Plastic Waste Management Rules, 2016, through the Plastic Waste Management (Amendment) Rules, 2024.The Plastic Waste Management Rules, 2016, along with the amendments in 2024, represent a comprehensive approach to tackling plastic pollution in India. There are other initiatives by GoI to tackle the Plastic Waste Management like :

By integrating agricultural plastic waste management into these broader initiatives, there is an opportunity to address the unique challenges posed by plastic use in agriculture. A first approach could be, for example, the gradual adoption of measures enabling the agricultural sector to comply with the International Voluntary Guidelines and Standards defined by the FAO (Food and Agriculture Organization of the United Nations) and the WHO (World Health Organization). Collaborative efforts can drive innovation, awareness, and systemic change, ultimately leading to more sustainable agricultural practices and a reduction in plastic waste. Institutional financing agencies play a crucial role in enhancing agricultural waste management and addressing plastic waste through various initiatives in India. Their involvement not only supports sustainable practices but also aligns with the Government of India's (GoI) objectives in promoting environmental sustainability and circular economy.

Looking at some on field examples to support the above strategies are mentioned below:

In various states particularly in Maharashtra and Gujarat NAFED has supported funding for the installation of plastic mulch, which helps conserve moisture and improve crop yields. In rural areas, particularly in Uttar Pradesh and Maharashtra NABARD has actively encouraged Bioenergy projects that generate fuel from Agricultural waste.

Other initiatives

Access to Credit: Offering loans with favourable terms for purchasing technology, such as RS and GIS systems

Capacity Building: Partnering with agricultural extension services to provide training on financial management related to sustainable practices.

Insurance Products: Designing insurance schemes that cover risks associated with adopting new technologies.

Incentive Programs: Collaborating with government schemes to offer incentives for farmers adopting sustainable methods.

Conclusion

Sustainable Soil and Water Management, bolstered by Remote Sensing and GIS technologies, holds immense potential to revolutionize agriculture both in India and globally. The development of a resilient and thriving agricultural sector can be achieved while also conserving natural resources. As we navigate the complexities of modern agriculture, embracing innovative practices and technologies will be vital in overcoming challenges. The cooperation of government, financial institutions, and the farming community has the potential to create a more sustainable, robust and resilient agriculture ecology. The path toward sustainable agriculture must be rooted in a deep understanding of local contexts, continuous learning, and the willingness to adapt to changing circumstances. By harnessing the power of technology and fostering a culture of sustainability, we can ensure that agriculture thrives for generations to come.

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