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Agricultural Precision: Transformation and Sustainability

Yohanes Parlindungan Situmeang*; Ni Luh Putu Sulis Dewi Damayanti; Anak Agung Sagung Manik Chindrawati

Master of Agricultural Science, Postgraduate Program, Warmadewa University, Denpasar, Bali, Indonesia
*Corresponding author: ypsitumeang63@gmail.com

Abstract

Agriculture, a crucial provider of food and raw materials, is evolving in response to technological advancements and population growth. Precision agriculture (PA), coupled with biochar utilization, has emerged to address global challenges such as resource scarcity, climate change, and rising food demands. PA employs IoT sensors for plant monitoring, enhancing efficiency and sustainability. The growing role of technology has sparked concerns about the environmental impact of modern agriculture, necessitating a balance between productivity and environmental preservation. Biochar, produced through biomass pyrolysis, offers soil benefits like improved structure and water retention while reducing CO_2 *emissions and enhancing nutrient availability. Despite challenges like environmental variation and cost, opportunities lie in advanced research, partnerships, policies, waste management, and carbon footprint reduction. This literature study highlights the synergy between precision agriculture and biochar, showcasing potential for transformative and sustainable agricultural practices that address global food needs while safeguarding the environment.*

Keywords: *Biochar, sustainable agriculture, precision agriculture*

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1. Introduction

Agriculture as one of the main pillars in providing food and raw material needs, has undergone a significant transformation along with technological developments and world population growth. To respond to global challenges such as limited resources, climate change, and increasing food demand [1], the concept of precision agriculture emerged that aims to revolutionize the way agricultural practices are viewed and implemented [2]. In order for the agricultural industry to reap the many environmental and economic benefits that precision agriculture technology has demonstrated [3]. Precision Agriculture consists of near and remote sensing techniques using IoT sensors, which help monitor the condition of plants at various growth rates [4]. Precision agriculture involves obtaining and processing large amounts of data related to plant health. Various parameters are involved in plant health, including water level, temperature, and others. Technologies such as satellite navigation, sensor networks, grid computing, ubiquitous computing, and context-aware computing support those domains to enhance monitoring and decision-making capabilities [5], all of which have opened the door to optimizing land management, water use, fertilization, and crop protection with unprecedented precision, due to technological advances and size reductions, sensors have become involved in almost every sphere of life [6]. Precision agriculture has increased the level of competition for raw material supply companies [7], [8]. By applying technology in agricultural practices, it can provide an opportunity to bridge the gap between global food needs and environmental protection.

An important element that can support the success of precision agriculture is the use of biochar in agricultural systems. Biochar is a product of biomass pyrolysis, such as agricultural waste and wood, which produces stable carbon material and has physico-chemical properties favorable to the soil [9], [10]. The application of biochar on agricultural soils has great potential benefits in waste management, carbon sequestration, greenhouses, gas reduction, water and soil remediation, and soil fertility [11], [12]. The use of biochar in agriculture can increase water retention, improve soil structure, and increase nutrient availability for plants [13]. In addition, biochar also has the potential to store carbon in the soil for a long period of time, which can help in mitigating climate change [14, [15]. In this context, this paper aims to explain how precision agriculture can contribute to transformation and sustainability in the agricultural sector. More specifically, this journal will discuss the linkage between precision agriculture and the use of biochar as one of the important elements in achieving this goal. By combining advanced technologies in agriculture with the benefits offered by biochar, it is hoped that agricultural systems can be improved sustainably, resulting in higher production while maintaining environmental integrity.

2. Materials and Methods

The method used in the preparation of this paper is the literature study method. The literature used is scientific articles that have been published in national and international journals in the last 10 years. Search for online-based scientific articles on portals such as Google Scholar (GS), Neliti, Research Gate, PubMed, Science Direct, Springer, Elsevier, and so on with the words precision agriculture, agricultural transformation, and sustainable agriculture.

3. Results and Discussion

3.1. Precision Agriculture: Transformation and the Concept of Sustainability

Sustainable agriculture and food systems need to provide adequate and nutritious food for everyone while minimizing environmental impact and enabling producers to earn decent livelihoods [16]. Most agree that agriculture and food systems need to be urgently changed in order to achieve progress on some of the Sustainable Development Goals (SDGs) [17]. Food systems are strongly linked to many sustainability challenges such as climate change, biodiversity loss, water scarcity, and food insecurity [18]. The sustainability transition can be defined as a process of long-term, multidimensional, and fundamental transformation through which existing socio-technical systems shift to more sustainable ways of production and consumption [19]. In agriculture, the idea of sustainability transition applies to the transition from an agri-food system whose primary goal is to increase productivity, to one built on broader sustainable agriculture principles [20]. The transition to food sustainability refers to structural changes that give rise to new, more sustainable ways and practices of production and consumption [21].

3.2. Biochar and Sustainable Agriculture

Biochar is a product of pyrolysis or heating of biomass, such as plant litter, wood, or agricultural waste, at high temperatures and with little or no oxygen [22], [23]. This process converts organic matter into material that is rich in carbon and has high stability. Biochar has a number of physical-chemical properties that make it a material that has the potential to provide significant benefits to sustainable agriculture [24]. The biochar production process involves heating biomass under conditions without oxygen or with a limited amount of oxygen [25], [26]. This process removes most of the organic components in the biomass, leaving behind solid materials rich in carbon and minerals. At higher temperatures, biochar is formed and can be used as a soil enhancer [27]. Biochar has the ability to absorb and store water in its pores. This is important to increase water availability for plants, especially in areas with water shortages or dry seasons [28]. The presence of biochar in the soil can improve soil aggregate structure, reduce compaction, and improve drainage, plant roots to grow better and access better nutrients.

Biochar has a large surface and surface charge that can hold nutrient ions such as nitrogen, phosphorus, and potassium that help reduce nutrient loss through the leaching process and increase nutrient availability for plants [29], [15]. Biochar has high carbon stability, meaning that the carbon contained in biochar can persist in the soil for a longer time than the original biomass [30]. This can contribute to long-term carbon storage in soils. The use of biochar in agriculture can provide several benefits. Biochar can be applied to the soil as an enhancer to increase soil fertility and productivity [31], [32]. By increasing water retention capacity, biochar helps reduce irrigation needs, reduce water wastage, and increase crop resistance to drought [33], [34].

3.3. The Linkage Between Precision Agriculture and Biochar

Precision agriculture and the use of biochar are strongly intertwined in the context of sustainable agricultural development [35]. The integration between these two concepts can result in significant synergies in improving the efficiency, productivity, and sustainability of agricultural systems [36]. Precision agriculture technologies, such as the use of drones and soil sensors, can enable more precise and efficient application of biochar [37]. Spatial mapping and data analysis can help identify areas that require increased soil fertility through the use of biochar which can prevent wastage of materials and resources by directing biochar applications only to areas of need. Precision technology can enable more detailed mapping of farmland, identifying differences in soil texture, acidity levels, and other factors affecting biochar absorption and effectiveness [38]. This allows the dosage and method of application of biochar to be more in line with soil characteristics, which can increase the benefits obtained from biochar [39]. The use of biochar in agricultural systems can help improve soil conditions for the optimization of sensor technology [40].

Biochar can improve soil conductivity and nutrient availability, which supports the sensor function in monitoring plant growth conditions [41]. Thus, precision agriculture can be improved with accurate information about the health and needs of plants. The use of biochar as a soil enhancer can help reduce carbon dioxide emissions into the atmosphere and store carbon in the soil in the long term [42]. Precision agriculture makes it possible to measure the impact of these carbon stores more accurately. The increase in crop productivity resulting from the application of biochar also contributes to reducing pressure on new land that must be converted to agriculture [43]. Biochar can be produced from agricultural and forest biomass waste [44]. Precision agriculture approaches can help in the management and collection of this waste more efficiently. By turning waste into biochar, precision agriculture contributes to waste reduction and harnesses previously untapped resources [45], [46].

3.4. Future Challenges and Opportunities

The integration between precision agriculture and the use of biochar offers great potential in achieving more efficient, sustainable, and productive agriculture [37]. However, the implementation of this concept is also faced with a number of challenges and opportunities in the future. Challenges such as variability in soil texture, chemical composition, and environmental micro conditions can affect biochar response and precision agriculture technology [47]. Complex adjustments are required to ensure that biochar applications and precision technologies are on target in overcoming this variability. In addition, there are various types of biochar derived from various biomass raw materials and production processes [48]. The selection of the type of biochar that suits the soil and plants grown requires a deep understanding of the characteristics of biochar and the needs of plants [49]. Crucially, the implementation of precision agriculture technology and the use of biochar may require significant initial investment. This can be an obstacle for farmers or agricultural entrepreneurs who have limited funds.

The application of precision agriculture also has opportunities that can be seen such as, continuous research in the development of precision agriculture technology and a deeper understanding of biochar can open up new opportunities to overcome existing challenges. This includes the development of more advanced sensor technology, identification of the most suitable type of biochar, and research on the interaction of biochar with the environment [50]. The integration of precision agriculture and biochar also provides opportunities to better manage biomass waste [51]. This can reduce the environmental impact of waste and generate valuable resources. This integration can make a significant contribution to reducing carbon emissions and mitigating climate change. This potential can be the basis for international cooperation in tackling climate change.

4. Conclusion

The integration between precision agriculture and biochar has great potential in improving the efficiency, productivity, and sustainability of agricultural systems. Precision agriculture technology enables more precise and efficient application of biochar. The use of IoT sensors and detailed land mapping enables the application of biochar according to soil characteristics, increasing the benefits derived from biochar. Biochar can also improve soil conductivity, nutrient availability, and carbon storage in the soil. While there are challenges such as environmental variability, selection of appropriate biochar types, and implementation costs, opportunities are also available. By combining precision agriculture technology with the benefits of biochar, it is hoped that agricultural systems can be improved sustainably. Efficient and productive agriculture can be achieved without compromising environmental sustainability. In facing these challenges and seizing opportunities, collaboration between different parties is key to developing sustainable solutions for the future of agriculture.

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