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The Importance of Variable Rate Irrigation in Lowering Greenhouse Gas Emissions in the Agriculture Sector: A Review †

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Abstract: Agriculture is extremely vulnerable to climate change, creating more difficult challenges. Presently, the agricultural sector contributes to between 19 and 29% of all global greenhouse Gas (GHG) emissions. Methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) are the main types of greenhouse gases generated by the agricultural industry. Energy use before and after farms, as well as shifting ground carbon stocks above and below as a result of changes in land use, are major sources of CO_2 emissions. There has been a trend in recent years toward lowering GHG emissions in the agriculture sector. Precision agriculture Technologies (PAT) address the field's temporal and spatial variability to maximize the usage of agricultural inputs (i.e., irrigation, fuel, and fertilizers). The PAT can keep or increase productivity while lowering GHG emissions from agricultural activities, whereas the variable rate irrigation (VRI) approach is helpful in this scenario. Recent research shows that VRI has a significant potential to mitigate GHG. The present study reviews research related to VRI that address the reduction in GHG emissions.

Keywords: agriculture; precision agriculture technologies; variable rate irrigation; drip irrigation; water management

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1. Introduction

Droughts, floods, and locust outbreaks are growing more common, and crop yields are decreasing; however, these abrupt climate changes are less concerning than the already existing issues for farmers worldwide [1]. Food demand is increasing as a result of variable diets, and the population is expanding in many regions of the world. The world will need to produce nearly 70% more human-required food to meet the needs of an estimated 9 billion people by 2050, making the problem of food security even more difficult [2]. The use of chemical fertilizers with pesticides and animal wastes in agricultural activities accounts for about 30% of all GHG emissions. This rate will undoubtedly continue to increase because of the rising global populations, increased food demand, as well as demand for dairy and meat-made products, and the intensification of agricultural processes [3,4].

The rise of modern technologies, which not only make farming sustainable but also boost output, food safety, and security while lowering GHG emissions, is the silver lining in this current situation [5–7]. There has been a trend in recent years toward lowering GHG production in the food production sector, but extensive efforts should be made in this direction to uphold global climatic assurances. The global warming potential (GWP) of methane is 25 times more than that of CO_2 over a period of 100 years. The conversion of microbial nitrogen (N) in soil and manure, as well as the dung and urine left behind by grazing animals, is the main source of nitrous oxide. Over a 100-year timeline, nitrous oxide has greater GWP (298 times) than CO_2. About 37% of all agricultural emissions in Europe come from agricultural soils, mostly as a result of synthetic N fertilizers and animal dung in the soil [8,9]. An effective long-term method for reducing climate change is the active management of cultivated soils using the right technologies and agronomic practices. There is overwhelming evidence that, in areas where PA is extensively practiced, water and fertilizer use can be reduced by 20 to 40% without affecting yields, and in some cases can even increase output [10–12].

Precision agriculture technologies (PAT) consider the field's spatial and temporal changes to maximize the usage of agricultural inputs (e.g., irrigation, fuel, and fertilizers). Currently, advanced technologies, e.g., (1) variable rate of nutrient application (VRNT), (2) variable rate of irrigation (VRI), (3) variable rate pesticide application (VRPA), (4) machine guidance (MG), (5) precision physical weeding (PPW), and (6) variable rate planting/seeding (VRP/VRS) are being used in developed countries to boost agricultural production. These variable rate advanced technologies can maintain or increase productivity while lowering GHG emissions from agricultural activities. Policymakers can evaluate the utility of incorporating PA into upcoming agriculture and climate policy tools by examining the role that these tools play in lowering GHG releases and raising farm output. This study focuses on evaluating precision water application techniques, which are suitable for reducing GHG emissions and enhancing overall farm productivity.

2. Greenhouse Gas Emissions in Agriculture Sector

The greenhouse gas emissions from the agriculture sector are relatively high and have a significant impact on climate change and global warming. Significant levels of non-CO_2 emissions, such as methane and nitrous oxide, are released by agricultural operations from crop production and the raising of livestock. The sources and processes of GHG involved in the agriculture sector are shown in Figure 1. According to the US Environmental Protection Agency, in 2020, the agriculture sector accounted for approximately 11% of GHG emissions compared to other sectors, e.g., commercial and residential—13%, land use and forestry—13%, industry—24%, electricity production—25%, and transportation—27% [5,13,14].

As bacterial activity increased under anaerobic conditions with irrigation, more CH4 emissions were produced, indicating that irrigation techniques can have a significant impact on GHG emissions. Additionally, variations in soil moisture have an impact on the redox potential of the soil, which has a substantial impact on the rates of soil GHG emissions [3,10,15]. Therefore, irrigation practices need to be modified and the amount of water required to irrigate the crops must be scheduled according to the crop water requirement to lower GHG emissions. VRI technology is an option that fulfills the spatio-temporal water demands of the crops.

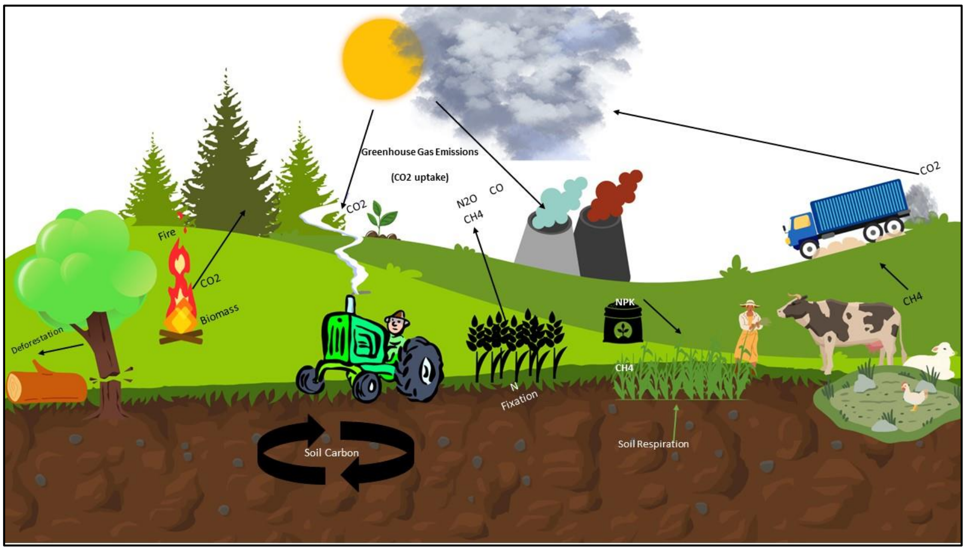

Figure 1. Greenhouse gas emissions in the agriculture sector (Picture credit: Saddam Hussain and Muhammad Habib Ullah).

3. Role of VRI in lowering GHG Emissions

According to a recent study, drip irrigation can significantly lower GHG emissions from soil and sustain the quality of the air without compromising forage crop production. Moreover, the amount of irrigation and nitrogen fertilization is positively correlated with N_2O emissions [1,5,13]. Andrews et al. (2022) [9] found that emissions of CO_2, N_2O, and NO are reduced by up to 62% through subsurface drip irrigation. When N fertilization is paired with accurate precipitation forecasting or scheduled irrigation, GHG emissions can be further decreased. Therefore, a drip irrigation system reduces GHG emissions more than a flood irrigation system. Moreover, the crop water productivity can also be enhanced by adopting an optimum irrigation schedule [4]. If the irrigation method, duration, and amount are modified according to their needs, it can further significantly reduce the GHG emissions.

An irrigation system can optimize irrigation application with the use of cutting-edge technology known as VRI. Since most fields are not uniform, when water is applied evenly, certain portions of the field can be overwatered, while others might stay too dry. This not only affects yield but also alters the GHG emissions cycle. The VRI technology has the potential to reduce over-watering, under-watering, and runoff, ultimately improving soil health and sustains the ecosystem. VRI's contribution to the reduction in greenhouse gas emissions lies in the proper utilization of water, thus reducing the need for energy through pumping. Moreover, proper irrigation schemes prevent extreme soil moisture utilization that increases N_2O emissions. The irrigation water can be saved by around 8–20% using the VRI technology. Many other studies also reported a reduction in water use and an improvement in irrigation efficiency using VRI technology [1,5,9,13]. Hence, the GHG emissions are linked to soil water availability, which depends very much on the amount, timing, and method of irrigation.

4. Conclusion

Irrigation plays an integral role in crop growth, health, and productivity. Precision water management can help to reduce GHG emissions and mitigate climate change. The VRI technology distributes the right amount water to plants and at the right intervals to satisfy the crop water requirement. In addition, less water needed for irrigation requires less pumping energy, powered by either fossil fuel or electricity, indirectly impacting greenhouse gas emissions. This study concludes that a suitable irrigation scheduling and irrigation technology can be used, i.e., VRI reduces GHG emissions. The VRI technique boosts the yield of grains and irrigation efficiency and reduces GHG emissions.

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