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Conservation Agriculture for Sustainable Crop Productivity and Economic Return for the Smallholders of Bangladesh: A Systematic Review

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ABSTRACT

Agricultural farming is a complicated system that involves continuous interactions among its multiple components over a period of time. The series of activities involved in farming practices have enormous contributions to ensure food security for the humanity. With the passage of time, agriculture sector faces diversified challenges like high food demand of rapidly growing population, scarcity of available resources and adverse effect of climate change. In developing countries like Bangladesh, food sufficiency is mostly achieved through intensive farming which has detrimental effects on natural resources, surrounding environment, and the whole ecosystem. The review attempts to discover the potentials of conservation agriculture practices for sustainable crop productivity and economic profitability of smallholder farmers in Bangladesh. This study revealed that conservation farm management practice is a cost-effective modernized technique that has the ability to accelerate crop productivity and farmers income through minimum utilization of agricultural inputs. Although the concept of conservation agriculture is widely practiced in other parts of the world, Bangladesh is experiencing a slow rate of adoption during the last few years. The policy implication of the study suggests that the government should take coordinated and combined initiatives involving both public and private sector organizations to incorporate this concept into the mainstream agricultural system of Bangladesh.

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Introduction

Agriculture is considered as the backbone of Bangladesh supporting the livelihood of majority of the population (Ministry of Agriculture, 2021). The agriculture sectors contributed 11.6% to Gross Domestic Product (GDP) of the country (World Bank, 2021). The role of the agriculture sector to achieve economic prosperity in Bangladesh is beyond these proportionate contributions of the sub-sector to the country's GDP while 67% of the total population belongs to the countryside and a notable proportion (43%) of the total labor force is working in this sector (BBS, 2021). For attaining self-sufficiency to fulfill the food demand of the large population of Bangladesh, priority was given to increasing crop productivity through intensive farming (Akteruzzaman et al., 2012). The concept of 'Green Revolution' emerged in 1960s helps to enhance crop productivity within a short course of time but continuous use of fertilizers and pesticides, which are synthetic in nature affects soil properties reducing soil fertility (Kafiluddin & Islam, 2008). Agricultural intensification has detrimental effects on components of nature such as air, water, soil, and the population of microbes (Montgomery, 2007; Kassam et al., 2013; Dumansky et al., 2014). Traditional agricultural practices based on deep ploughing reduce soil organic matter content, and accelerate the processes of soil erosion, salinity intrusion, and leaching of soil nutrients (Mandal et al., 2020; Rani et al., 2021; Yadav et al., 2014; Pandey et al., 2015; Tomar et al., 2014; Bisht et al., 2014; Singh et al., 2013). On the other hand, the world's climate is changing rapidly due to anthropogenic activities. The extreme climatic catastrophes are also frequent and will continue to increase throughout the next few decades (IPCC, 2014). In case of Bangladesh, the rate of per capita CO_2 emission is comparatively low (0.5t/year) compared to other countries but it is one of the most victimized countries due to extreme climatic events (FAO, 2013). Adapting to the effects of climate change with the aim of fulfilling the food demand is the crucial challenge for the agriculture sector in developing countries like Bangladesh (Brouziyne et al., 2018; FAO, 2013). An increasing trend of average temperature prevails in Bangladesh with intensified dry and wet season (Basak et al., 2013). For sustainable agricultural productivity, resources preserving conservation farming approach is the most viable solution to cope with the future challenges.

Conservation agriculture is a kind of resource preserving technique that allows least tillage practices, maintenance of soil coverage, management of crop residues and crop rotation practices with sustainable crop productivity and economic profitability (FAO, 2007). But due to the use of traditional farming systems like deep ploughing, long duration mono cropping practice, low use of organic or green manure, lack of balanced fertilization and residue management the soil quality is severely affected in most of the areas of Bangladesh (Kafiluddin & Islam, 2008). These kind of conventional farming practices resulted in reduced crop yield and economic loss. Only a small proportion of farmers (8-10%) across the globe follow conservation agriculture practices amid it assists farmers to enhance their economic profitability through minimum use of resources, low input costs and conserving natural ecosystem (Willer et al., 2008; Parrott et al., 2006; Lampkin & Padel, 1994). The conventional agricultural practices stimulate the loss of water and nutrients due to deep tillage practices and causes the emission of CO_2 contributing in global warming. On the other hand practicing conservation agriculture helps in conserving the natural ecosystem with the minimum usage of resources, eco-friendly pest management and maintain soil quality (Reicosky, 2001). Maintenance of cover crops have positive impacts on soil aggregation resulted in accumulation of soil nutrients and enhances population of beneficial microorganisms. The beneficial soil microbes can improve the capacity of water absorption, nutrient availability and soil aeration (Clapperton, 2003).

From the study of previous literature, it is found that studies conducted in Iowa State of Mexico emphasizing on maintenance of crops as a protecting cover, rotation of crops, and minimum soil destruction that helps to reduce soil erosion and nutrient loss (Mine et al., 2014). Nguema et al. (2013) conducted a study on impacts of conservation farming practices and found that conservation agriculture practices contributed to increase household income of farm families in Ecuador. A comparative study on economic, gender and labor productivity of conservation farming practices in India founded that cultivation of legumes without the application of zero or minimum soil cultivation had better economic benefit compared to conventional agriculture (Lai et al., 2012). Conservation farming practices performed better compared to organic farming and traditional farming practices to improve soil health with minimum emission of nitrogen and green-house gases noticed by Aune (2012). Akter & Gathala (2014) reported that mode of adoption of conservation practices by the farmers of Bangladesh affected by geographic location, cropping pattern and seasonal variability. Conservation agriculture practices also reported to have impacts on food security and rural livelihoods in Zimbabwe by improving crop productivity and family income (Tshuma et al., 2012). The above literature review indicated that worldwide consecutive studies were conducted on beneficial impacts of conservational agriculture but a very few of them are accomplished covering the geographic location of Bangladesh. This study would greatly contribute to understand the role of conservation farming practices for sustainable agricultural productivity and economic benefit of smallholder farming households located in Bangladesh. Therefore, the basic aim of this review study is to inspect how conservation agriculture practices contribute in achieving sustainable agricultural productivity as well as economic profitability of smallholder farming community of Bangladesh.

Materials and Methods

This research used a systematic technique of existing literature review (Tricco et al., 2018). This method is an effective and mostly preferred method to review the latest literature which allows to discover innovative knowledge in the relevant area of interest (Colicchia & Strozzi, 2012). This method of literature review brings an insight and logical diagnosis of formerly conducted research or current knowledge in the field of study to conduct the review. Moreover, a systematic literature review is more accurate and trustworthy process of literature review without any biasness (Mallett et al., 2012). This commonly used method of literature review enables the author to recognize, composite and evaluate all the available evidence or documents (qualitative or quantitative) for successful completion of the study (Van der Knaap et al., 2008; Mallett et al., 2012).

Significance of the study

Meeting the food demand of rapidly growing population becomes a major challenge for developing country like Bangladesh. Due to intensive land use and mostly mono cropping farming system soil fertility and productivity is reduced to a great extent (Akteruzzaman et al., 2012). In this case, conservation agriculture has great potentials for sustainable intensification to ensure food security and meet up of future challenges faced by agriculture sector in Bangladesh. Globally conservation agriculture becomes popular day by day but the rate is slow in developing countries like Bangladesh though it has beneficial impacts on agricultural productivity, resource conservation, low input use, climate change mitigation, and better economic return compared to conventional agriculture practices (FAO, 2016). To accomplish this review, a diverse data sources have been used including Web of Science, Science Direct, Journal Storage (JSTOR), and Scopus (Dias et al., 2019; Baier-Fuentes et al., 2019). The articles from databases were identified and used because of being peer reviewed and indexed in widely accepted scientific databases.

Searching article and inclusion

To search the articles the keywords such as conservation agriculture, agricultural or farm, productivity, sustainability, smallholders, economic benefit were used in the title of the study. Additionally the terms conventional agriculture, principles, impact, environment, prospects, challenges and Bangladesh were also used. This review was confined to the peer-reviewed articles and trusted documents of English language because of wider dissemination of useful knowledge, and information across the globe (López-Fernández et al., 2016).

The relevant research articles were identified by using the above-mentioned keywords while the other documents were excluded. To execute the review process a muti-stage screening technique was followed which involves go through the title or abstract of the study while the full or partial text of the articles were also read when it is required. A good number of articles were eliminated due to the duplication in nature. Based on the specific subject area, the irrelevant articles were eliminated while the studies those are relevant and related to conservation farming, and its potentials to enhance agricultural productivity, and aspects of economic benefit were finalized to accomplish this study.

Analysis of the articles

All the relevant and necessary information were extracted by reading the selected articles. The basic concept of conversation agriculture, comparative impact of conservation agriculture and conventional agriculture on farm productivity, environmental sustainability to mitigate climate change and economic benefit for the smallholder farmers of Bangladesh are the focal points of the study. Efforts were also given to discuss the future challenges of conservation agriculture practices to develop a revitalizing agro-ecosystem for sustainable intensification.

Findings and Discussion

Definition

Conservation farming is a cultivation technique which permits least disturbance of upper soil (zero tillage), maintenance of soil coverage, and crop alteration. It also focuses on population dynamics of soil microorganisms and triggers different naturally occurring biological process of the soil. This kind of activities result in improvement of water and nutrient use efficiency for sustainable farm productivity (Smith et al., 2016; FAO, 2016). Conservation farming is a natural ecosystem management system aims at sustainable crop productivity, economic profitability and food sufficiency by conserving the resources as well as environment (Friedrich et al., 2012). The basic pillars of conservation farming are: minimum tillage, usage of permanent soil coverage organic in nature and diversification of crops through crop rotation practice (FAO, 2016; Somasundaram et al., 2020). Conservation farming is a modernized technique that aims to ameliorate soil properties resulting in sustainable agricultural productivity and conservation of natural ecosystem (Shrestha et al., 2020; Yadav et al., 2017; Basavanneppa et al., 2017).

Historical background

The history of agriculture is ancient that has a commanding role throughout the process of civilization. The agricultural activities were started in Mesopotamia in the bank of the rivers named Euphrates and Nile since 3000 BCE (Friedrich et al., 2012; Hillel, 1998). During the primitive stage the tillage or cultivation equipment were mostly operated by human labor or animal draft power while mechanized tillage equipment became available in the nineteenth century after the industrial revolution (Friedrich et al., 2012). Deep tillage causes massive destruction of soil surface, and resulted in the emergence of idea like sowing of seeds by using seeding equipment without tillage practice (Farooq et al., 2011; Friedrich et al., 2012). Conservation farming was first introduced in the 1940s in the North America, and it took a good period of time to make this farming practice become popular among the farmers. During the 1970s, due to high price of fuel, destruction of soil motivate the farmers to adopt conservation farming practices in commercial farming (Farooq et al., 2011). During that period, the idea of zero or minimum tillage was started to practice in Brazil while zero tillage, and the idea of mulching were at the early stage of practice in West Africa (Friedrich et al., 2012; Lal, 1976; Greenland, 1975). The adoption rate of conservation farming took 20 years to reach at a satisfactory level (Farooq et al., 2011; Derpsch et al., 2010). Conservation farming gains popularity during the period of 1990s and started to spread rapidly throughout the world resulted in significant agricultural growth in Argentina, Paraguay, and southern part of Brazil (Kassam et al., 2013; Friedrich et al., 2012). The high acceptability of conservation farming practices were able to attract the attention of well renowned prospective organizations like International Fund for Agricultural Development (IFAD), Food and Agriculture Organization (FAO), World Bank, and the Consultative Group for International Agricultural Research (CGIAR) to develop resilient farming technique (Kassam et al., 2013). During 2015-2016 conservation agriculture adopted by farmers covering 12.5% of total cultivable area (180 m ha) accounted for significant increase compared to the year of 2008-2009 (Kumar et al., 2017). Presently, conservation farming technique is a prospective system of farming in North America, Brazil, Argentina and Paraguay (Kassam et al., 2013). Conservation agriculture is the most viable technique of farming as this is suitable for diversified crops in a wide range soil and climatic condition to enhance sustainable agricultural productivity.

Basic principles of conservation agriculture

Minimum soil disruption

Most of the farmers followed traditional farming system that requires tillage practices for any crop cultivation while minimum or zero tillage is required to follow conservation agriculture practices. In case of conservation agriculture, crop seeds are sown directly with minimum tillage practices after the collection of the earlier crop. Practicing of zero or minimum tillage has several beneficial impacts like it replenishes the top soil by reducing erosion caused by air and water and also saves labor cost and time. Moreover, it also conserves soil moisture by facilitating the rate of soil infiltration with improvement of soil health.

Maintenance of permanent soil coverage

Crop residues can be used to maintain permanent soil coverage. Generally, crop residues are living plant parts like leaves, stalks, straws, roots etc. kept over after harvesting of the crop. The top soil surface is covered with living mulch materials conserve soil moisture, suppress weed growth, and enhances soil fertility. Cover crops can be used as live mulch materials can be intercropped with the main crops. Use of permanent soil coverage has several advantage such as it helps to decrease soil erosion, minimizes weed growth by reducing germination and improves nutrient use efficiency by facilitation the process of nutrient reclamation.

Crop diversification

Cultivation of same crops year after year in the same field which is termed as monocropping is the main feature of conventional agriculture causes low soil nutrient status, and organic matter content. On the other hand, conservation agriculture facilitates crop rotation and intercropping practices. Due to cultivation of crops having heterogeneous root length enhances the uptake of nutrient from different soil layer improve soil fertility and productivity. Inclusion of leguminous crops help to increase the status of nitrogen in the soil. Crop diversification also minimizes disease and pest infestation which greatly reduces the cost of production of various crops.

Conservation farming practices and their impacts on overall soil and crop management as compared to traditional practices

Conservation farming is a sustainable approach of production consists of a number of farming techniques adjusted according to the requirements of the crop species and regional climatic context. Various farming practices prevent soil depletion through conservation of natural resources with the aim of optimizing farm output. In conventional agriculture deep tillage is practiced which enhances soil loss, depletion of essential nutrients, and low content of organic substances while in case of conservation farming minimum or zero tillage is practiced to cultivate varieties of crops. Zero or minimum tillage practices maintain soil structure and triggers the beneficial processes like microbial activity, soil aeration, and the efficiency of water, and nutrient use (Bhatt, 2017; Hobbs et al., 2008). The major impacts of minimum soil disturbance includes prevention of plough pan formation, improve soil organic substance, nutrient recycling capacity, and minimum occurrence of weed. It also significantly contributes in reduction of production cost, control of green-house gas emission and minimization of air pollution through burning of crop residues and fuel (Laxmi et al., 2007). The cropping pattern of rice-wheat mostly followed zero tillage but it can also be practiced in case of sowing pulse crops like lentil, mustard, chick pea and cereals like rice and maize (CSISA, 2018). The surface seeding is a kind of conservation agriculture practice that involves broadcasting of wheat seeds on the moisture rich soil surface before or after the completion of harvest of previous crop (rice). In this practice soil structure is kept as it is and soil moisture helps in seed germination.

The traditional agriculture practice includes high labor cost, excessive weed growth and burning of crop residues while this cultivation technique is appropriate for marginal and smallholder farmers because of low labor and input cost, minimizing the weed growth and high content of organic substances (Yadav, 2019). In most of the cases, conventional agriculture method resembles plantation of crops in moisture rich soil. The use of flood irrigation system causes loss of water, formation of soil crust, excessive use of fertilizers due to leaching and run off loss and high incidence of pests and diseases (Tripathi & Das, 2017). Increasing crop productivity with limited resources (land, water), and sustainable management of environment is a major challenge of agriculture sector. In this case inclusion of bed planting method can be a viable solution that involves making of raised beds and furrows are made between the adjacent rows (Tripathi & Das, 2017). The top surface of the beds is used for seed sowing while the furrows are used for different intercultural operations like weeding, irrigation, fertilization and drainage (Tripathi & Das, 2017). Raised bed system has the advantage of desired placement of fertilizers, and management of weed by using mechanical techniques (Singh et al., 2010; Sharma et al., 2002). Bed planting system has the capacity to save 30-50% water used for irrigation compared with traditional system of plating (Singh et al., 2010; Naresh et al. 2010; Hossain, 2001). Conservation agriculture practices facilitates intercropping and diversification of crops while crop yield is boost up to 20% (Pandey et al., 2013).

Commonly practiced traditional rice cultivation system involves raising of seedlings in the nursery bed, and transplantation of 20-25 days seedlings in the rice field prepared by soil puddling. Puddled transplanting system of rice cultivation causes wastage of water through evaporation and percolation, and enhances the formation of hard plough plan that reduces soil aeration (Kaur & Singh, 2017; Farooq et al., 2011). The cultivation of transplanted rice requires high water and labor cost that drastically reduces the economic benefit of the farmers (Kaur & Singh, 2017; Pandey & Velasco, 1999). For the betterment of water and nutrient use efficiency, low labor cost and minimum emission of green-house gas an alternative cultivation technique of sowing the seeds directly in the rice field can be practiced. This technique reduces the cost of irrigation water, labor, fertilizer requirement, decreases green-house gas emission and better crop productivity (Kaur & Singh, 2017).

Precision farming is technology based farm management practice which enables collection, management and analysis of different levels of data to facilitate decision related to farm management for effective use of available resources with better productivity and profitability. Precision agriculture based on the principles of Global Navigation Satellite System (GNSS), and Global Positioning System (GPS) can be renamed as location specific crop management practices. In developing countries like Bangladesh where average farm size is 0.5ha and where 88.5% of the farmers have farm size less than 1 ha (BBS, 2018). Small and fragmented farm size causes hindrance for the development of sustainable farming system in Bangladesh. Precision agriculture is an eco-friendly and profitable farming system that ensure effective use of water, fertilizers, pesticides and other inputs (Solomon, 2020). Precision farming also help to minimize the green-house gas emission and create income generating facilities for skilled labor (Kumar, 2020). Despite having a good number of advantages the adoption scenario of precision farming is low because of involving high initial cost, requires long time to set up the system with expertise knowledge and skills, lack of infrastructural development and poor socio-economic background of farmers create obstacles for mass dissemination of this modern farming technique in Bangladesh.

Conservation agriculture for sustainable productivity and economic profitability for smallholder farmers

The economy of Bangladesh is largely depending on agriculture, as it creates employment opportunity for about

50% of the total labor force and also providing food for a population of over 160 million (BBS, 2018). The country is losing the cultivable land every year at a rate of 1% which is a major concern in upcoming days (MoA, 2021). In the process of technology adoption, an individual would will to accept any technology or practice if it has better advantages than the existing one.

Conservation agriculture has a wide range of positive impacts on agronomic management of crop farm by enriching soil organic matter content, minimizes weed growth by using crop residues or mulching, increase water and nutrient use efficiency (Saharawat et al., 2012; Jat et al., 2012; Shrestha et al., 2020), and increase the yield of diversified crops (Gathala et al., 2011). Crop residues have favorable impacts on soil amelioration, water infiltration, and control of soil loss significantly (Laxmi et al., 2007). It is evident from the findings that splash erosion can be controlled up to 85%, if 35% of the surface soil is surrounded by using organic residues or mulch materials (FAO, 2016). Conservation agriculture has sustainable economic benefit for the farmers because it is a time saving method that requires less agricultural inputs and labor requirement that can significantly reduce the production cost (Malik et al., 2005). An impact evaluation study on conservation agriculture was conducted by Uddin & Dhar (2016) found that conservation farming practices significantly increase farmers' income for the improvement of livelihood status than the non-adopter farmers in Bangldaesh. A comparative study was done by (Majumder et al., 2020) revealed that due to the adoption of conservation agriculture practices the productivity of crops including mustard, soybean, and rice were increased compared to conventional farming practices in coastal areas of Bangladesh. Conservation agriculture practices have positive impacts towards farmers' economic benefit and to improve soil quality in diversified areas of Bangladesh (Uddin et al., 2017). The low requirement of agricultural inputs and labor cost make this practice feasible and economically profitable for the smallholder farmers.

Conservation agriculture practices have better sustainability to save the environment and preserve natural ecosystem. It has several favorable impacts to improve the components of environment (soil, air and water), facilitates the process of carbon sequestration, and minimizes green-house gas emission.

Challenges involved in practicing conservation agriculture

Conservation agriculture has multiple positive impacts to improve crop productivity and economic benefit of farmers but the adoption of such kind of practices is not at satisfactory level. Conservation farming is widely practiced in Canada, Australia, United States, Argentina, and Brazil while in case of developing countries like China, India, Bangladesh and Zimbabwe the rate of adoption increased at a slow rate in the last few years (Kassam et al., 2013). The adoption of conservation farming practice is at medium level in case of Natore district of Bangladesh despite having a wide range of advantages than traditional agriculture (Poddar et al., 2017). Some major challenges create obstacles for wider dissemination and adoption of this potential farming practice at farmers' level. Most of the farmers do not have sufficient knowledge about the beneficial impacts and hands on knowledge about the location specific appropriate technology. To make the farming system productive and economically profitable, adequate knowledge on management practices of conservation agriculture is essential. Another notable constraint is poor socio-economic condition of the smallholder farmers. In case of developing and underdeveloped countries, farmers use crop residues as livestock feed or fuel purpose in most cases. The practice of burning crop residues to plant the succeeding crop in rice-wheat based cropping pattern is followed in India and neighboring countries (Laxmi et al., 2007). This kind of practice has detrimental impacts on organic matter status, and affecting the natural ecosystem. Farmers' are reluctant to adopt agricultural machinery for farming practices because of high initial cost with small and fragmented farm size make the agricultural equipment inappropriate for them. For better promotion and wider adoption of modernized technologies there should be a strong linkage between the relevant stakeholders like researchers, beneficiary farmers, extension staff and local leaders. Extension is a two-way communication between farmers and researchers. The nature and access to extension services of a country have a tremendous role for technology dissemination at farmer level (Rambhai, 1958).

Another important factor to be mentioned that, in most of the time, the outcomes of conservation farming practices are invisible during the early period of adoption (Abrol & Sangar, 2006). This also plays a crucial role for low adoption rate of this sustainable farming system.

Conclusion

The agriculture sector of Bangladesh is characterized by small fragmented land, low crop productivity, limited provision to agricultural technology and deterioration of environment. Ensuring food safety for the large sum of population, and mitigating the substantial impacts of climate change are the rising challenges in the upcoming days. In such condition, conservation farming practices have the viability to promote sustainable agricultural productivity by means of minimum use of inputs, conserve natural resources and economic benefit of the smallholder farmers. Moreover, it has the capacity to mitigate the negative effects of extreme climatic events, and environmental degradation. The policy implication suggests that the government should undertake a holistic approach for wider dissemination, and implementation of these farming practices at field level. Importance should also be given to increase knowledge, and skills of farmers through participatory training, and technology demonstrations with provision of incentives. Investments should be made to create cost effective agricultural technologies targeting the smallholder farmers of Bangladesh.

Conflict of interest

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