Dissemination pathways and impacts of low-carbon technologies on yields among Sawah rice farmers in Nigeria

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Abstract

The activities related to dissemination pathways and impacts of low-carbon technologies on anthropogenic emissions among Sawah rice farmers in Nigeria were described. It shows that many practices associated with Sawah technology can be categorized as low-carbon technology which is unwittingly adopted by rice farmers. Water management, alternate wetting and drying, rice intensification, planting green manure during the fallow season, and optimizing fertiliser management practices are some of the Sawah technology's features that are fully compatible with low-carbon technologies, while other features are only partially compatible. In terms of the mitigation potentials, Biochar, zero-waste systems of farming, and fertilization in double rice-cropping systems recorded the highest mitigation potentials with 7.24 to 8.43 t CO_2-eq ha^{-1}, 6.1–11.1 t CO_2-eq ha^{-1}, and 4.1 t CO_2 eq ha^{-1} yr^{-1} respectively. The prominent pathways for dissemination are on-farm demonstrations and field days, farmer to farmer, and expansion strategy for Sawah Eco-echnology for rice farming. These practices have therefore established that Sawah rice production technology contributes to the reduction of methane from rice fields and thus climate smart.

Keywords: Low-carbon technologies, yields, Sawah rice, mitigation, emission

INTRODUCTION

In Nigeria, rice production is a major agricultural practice where land allocation has been increasing from 2,269 to 3,500 hectares from 2012 to 2023 (USDA, 2023). In sub-Saharan Africa (SSA), rice is a major staple food that is grown under rainfed upland, rainfed lowland, irrigated lowlands, and deep-water environments as depicted in Figure 1. Rice production technology that focuses on lowland rice production was introduced in many African countries due to the increased yields that are twice as much as what is obtainable from upland rice production. Rice is less water efficient when compared with other crops as one kg of rice requires 3000-5000 liters of water (Cabangon *et al.,* 2014) or 1900 to 5000 liters of water to produce 1 kg of grain (Khairi *et al.,* 2015). Rice production is adversely affected when soil water is lower than in saturated conditions (Tuong and Bouman, 2003); water deficit-induced reduction in growth, flowering, and grain yield by 21%, 50%, and 21% respectively (Pirdashti *et al.,* 2004). Rice production in irrigated lowlands has been associated with greenhouse gas (GHG) emissions and sometimes four times the GHG emissions per ton of other cereal crops in the form of methane and nitrous oxide (Nalley *et al.,* 2014).

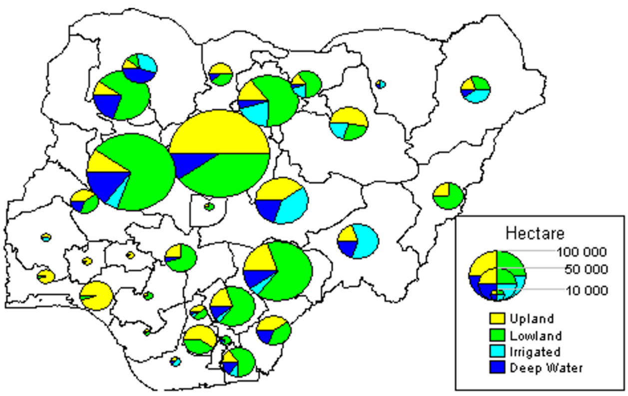

Figure 1: Rice production ecologies in Nigeria (Fashola et al., 2007)

Anthropogenic emissions are pollutants, such as greenhouse gases and aerosols, released into the atmosphere directly from human activities like burning fossil fuels, industrial processes, and deforestation. These emissions contribute to environmental issues, including air pollution, the greenhouse effect, and climate change. Examples of key human activities and the emissions they produce include transportation and power generation (CO_2, NO_x), agriculture (methane, nitrous oxide), and industrial processes (various gases and aerosols).

Rice production has dual functions of carbon sink and carbon source, transferring carbon to the soil through the synthesis of atmospheric carbon dioxide, ploughing back stubble, straw, litter, and emissions of carbon dioxide and methane from seed, fertilizer, pesticide, machinery, and transportation. However, rice production remains the largest emission source of CH_4, and accounts for 18% of total agricultural CH_4 emissions. Mohan *et al.* (2022) stated that a total carbon footprint of 6720 Kg CO_2 eq/ha was found for the cultivation, harvest, and post-harvest operations of rice production, with 1851 Kg CO_2 eq/ha from harvest and post-harvest processes and 4869 Kg CO_2 eq/ha for cultivation. Low-carbon rice farming improves environmental conditions by reducing greenhouse gas emissions, promoting better soil and water health, and increasing biodiversity through practices like alternate wetting and drying (AWD) and reduced agrochemical use. This approach also benefits farmers through increased incomes from

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lower costs and potential carbon credits, while contributing to global goals for food security and climate mitigation. Key environmental improvements include lower methane and CO_2 emissions, more efficient water use, healthier ecosystems due to less pesticide runoff, and improved soil organic matter (Huang *et al.,* 2024).

Nalley *et al.* (2014) reported that a significant greenhouse footprint through methane emissions is linked with rice cultivation due to labile soil carbon anaerobic decomposition; losses as carbon dioxide, nitrous oxides, and fossil fuel combustion through the process of fertilizer production, field operations, transportation, and post-harvest processing. EPA (2014) indicated that the potency of methane for greenhouse warming is over 21 times more than CO_2 over a 100-year period. IPCC (2021) estimated that approximately 55% of the global budget of GHG emissions from farm soils are due to rice production. Some factors affecting CH_4 emission from lowland rice include the number of drained days which reduced emission to 1.2 kg CH_4 ha^{-1} day^{-1} from flooded rice and water requirement is reduced by 30-50% (Anas *et al.*, 2022). Improved irrigation through flooded rice systems, conversion of lowland rice areas to non-agricultural uses, use of low-emission rice varieties have the potential for decreasing CH_4 emission (ASEAN-CRN, 2023).

According to Abe and Wakatsuki (2011), the term "Sawah" refers to "leveled and bunded rice fields with inlets and outlets connecting irrigation and drainage". ''Sawah" is a rice cultivation technology with components that focus on ploughing, puddling, and leveling often through power tiller, water and fertilizer management for increased rice production and involves the use of farmers' own man-made structures (bunds) to control water, conserve soil, control weeds and enhance uniform fertilizer distribution on the rice fields in order to maximize and sustain rice yields. Nwite *et al.* (2019) defined Sawah as "an Indo-Malaysian term for a rice paddy, that augments soil physical properties through ecological engineering in terms of bunding, puddling and leveling of lowland rice field for water control and management" as shown in figure 2.

MATERIALS AND METHODS

This paper examines the interdependence and conjunction that exist between low-carbon technologies and Sawah rice production technology. It posits that the dissemination pathways for Sawah technology facilitate the dissemination of low-carbon technology. A case study description of the process and activities establishing the similarities between low-carbon technologies and Sawah production technology was described and shows that many practices associated with Sawah technology can be categorized as low-carbon technology which is unwittingly adopted by rice farmers. This paper reviewed the features of both categories of technologies and draw lessons for further science.

This study combined field observation with Focus Group Discussions. Participatory research approaches are fundamental research tools for social understanding of embodied experience, which taps into lived experiences and guide research questions for social understanding (Olaniyan and Govender, 2023). Kemkes and Akerman (2019) found that through field observation, participants were able to narrate their understandings of collective actions' failures and the uncertainties surrounding the magnitude and timing of localized effects of climate

***Figure 2: Sawah on-field plot preparation** (Wakastsuki 2003)*

change. Olaniyan and Govender (2023) combined focus group discussions with in-depth interviews and participant observations to describe the response to climate change by root and tuber farmers in Nigeria. The combination of focus group data collection and interpretive phenomenology has utility in many types of studies, such as those that highlight the use of Indigenous knowledge in response to climate change. Focus groups were used as a data collection method to allow representations of multiple perspectives, and to derive key information from the consensus or discrepancies between focus group members (Leech and Onwuegbuzie, 2007). Data were analyzed as a reference group and no unique individual identifiers were included in the data nor results.

RESULTS

The results are organised into sections namely introduction of Sawah rice production technology, Sawah technology and the principles of alternate wetting and drying, list of low-carbon technologies associated with rice and their mitigation potentials, and Dissemination pathways of low-carbon technologies through Sawah rice production technology.

Sawah projects in West Africa were introduced by Japanese institutions, Integrated Watershed Management of Inland Valleys by Japan International Cooperation Agency (Figure 3). Sawah project by Shimane University; Kinki University Japan. The goal is the development

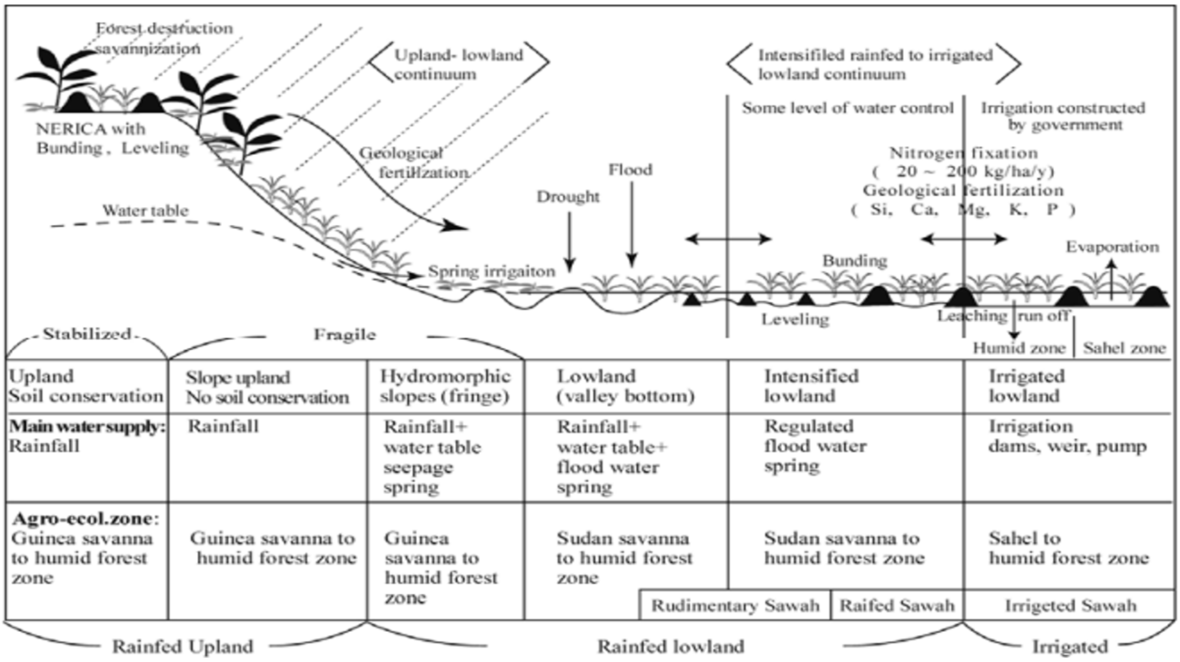

***Figure 3: Rice ecologies along a continuum of inland valley watershed and floodplains** (Wakastsuki 2003)*

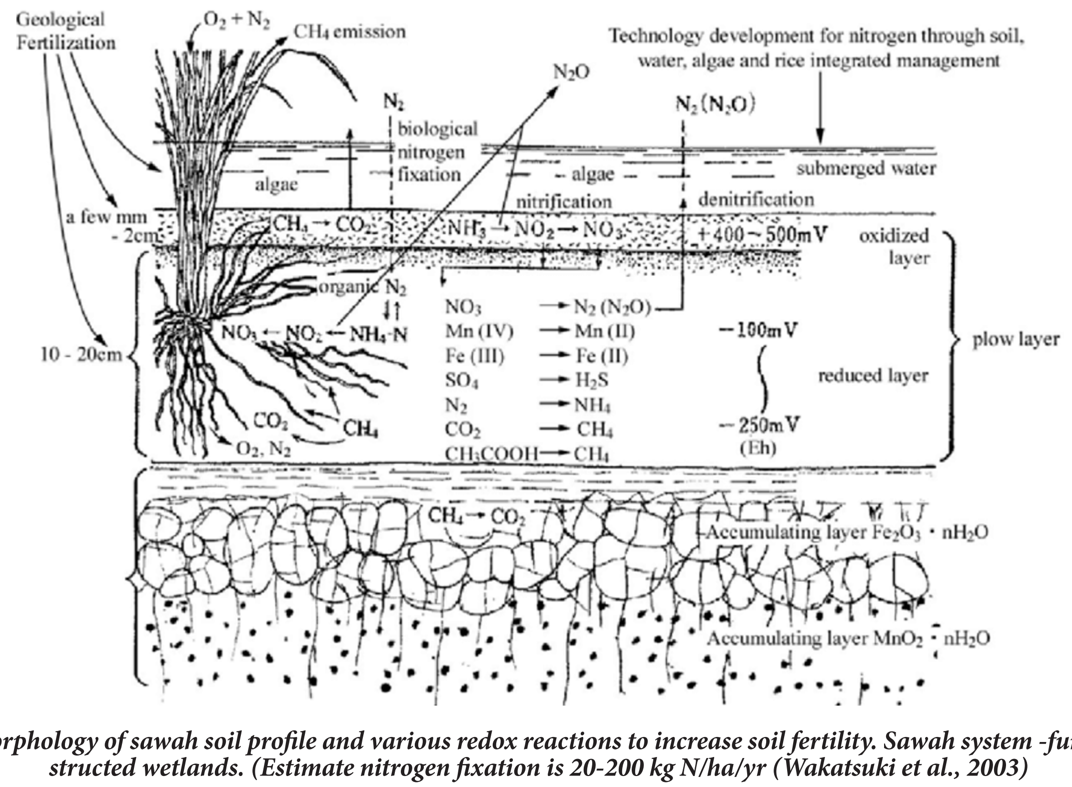

Figure 4: Morphology of sawah soil profile and various redox reactions to increase soil fertility. Sawah system -functional constructed wetlands. (Estimate nitrogen fixation is 20-200 kg N/ha/yr (Wakatsuki et al., 2003)

Table 1: Low carbon technologies identified with rice production

Technologies	Major impacts	Mitigation potential	Citation	Sawah feature
Zero-waste rice-based farming system	Eradicate crop residues combustion	6.1−11.1 t CO_2-eq ha^{-1}	Eduardo, 2019	Partial
Planting green manure in fallow season	Increases soil carbon Incorporation crop residue into soil	1.87 t CO_2-eq ha^{-1}	Xu *et al*., 2016; Shang *et al.,* 2016	Full
Manure / biosolids use	Promoting crop residue incorporation into soil, Increases soil carbon	1.54 to 2.79 t CO_2-eq ha^{-1} yr^{1}	DECCW NSW 2011	Partial
Compost	Promoting crop residue incorporation into soil, Increases soil carbon	1.10 to 1.80 t CO_2-eq ha^{-1} yr^{1}	DECCW NSW 2011	Partial
Zero tillage	Reduce irrigation water, Eradicate crop residues combustion, Reduce the cost of tillage by 40-50US$/ha, Reduced diesel by 70-90 liters per ha	0.36 – 0.488 t CO_2-eq ha^{-1}	Rahman *et al.,* 2021	Partial
Conservation tillage	Reduced or avoided tillage practices Reduced microbial decomposition Incorporation crop residue into soil	0.23–0.71 t CO_2-eq ha^{-1}	Chen *et al*., 2014; Xue *et al*., 2014	Partial
Tillage/residue management	Promoting crop residue incorporation into soil, Increases soil carbon	0.15 to 0.70 t CO_2-eq ha^{-1} yr^{1}	DECCW NSW 2011	Partial
Organic Farming	Reduce emission, Increase soil carbon Reduced use of agrochemical	1.68 - 2.67 t CO_2-eq ha^{-1} yr^{-1}	Adewale *et al*., 2016	None
System of Rice Intensification	Higher yields, Saves irrigation water, Reduced labor costs, Reduced pest and disease, Increased income	0.29 to 0.88 t CO_2-eq ha^{-1} yr^{1}	DECCW NSW 2011	Full
Adapted agronomy practices	Increased income, Reduced labor costs Reduced pest and disease	0.29 to 0.88 t CO_2-eq ha^{-1} yr^{1}	DECCW NSW 2011	Partial
Alternate wetting and drying	Saves water, Reduce methane emissions, Plant materials aerobic decomposition, Reduce methane emissions, Nitrogen-use efficiency increased	0.348 – 0.3527 t CO_2-eq ha^{-1}	Mboyerwa *et al*., 2022	Full
Rice varieties Pest-resistant genetically modified varieties Efficient use of nitrogen fertilizer varieties	Reduce the use of pesticides, Reduce the use of nitrogen inputs, Increase rice yield, Improve oxidation in the rhizosphere Improve rhizosphere transmission capacity Reduce CH_4 emissions	0.51–1.39 t CO_2-eq ha^{-1}	Fu *et al*., 2010; Xu *et al*., 2015	Partial
Planting-breeding technology	Aerate the paddy soil by burrowing, Increase redox potential, Lower CH_4 emission	0.78–2.12 t CO_2-eq ha^{-1}	Bhattacharyya *et al*., 2013; Xu *et al*., 2017	None
Fertilization in double rice-cropping system	Improve soil carbon sequestration Reduced fertilizer use Reducing nitrous oxide emissions	4.1 t CO_2-eq ha^{-1} yr^{-1}	Shang *et al*., (2010)	Partial
Slow Release N-fertilizer	Reduce leaching losses, Reduce N use and efficiency of N use, Reduce nitrous oxide emission by inhibiting nitrification with use of Neem coated urea/Sulphur	4.1 t CO_2-eq ha^{-1} yr^{-1}	Shang *et al*., (2010)	None
Pesticide reduction technology	Reduced herbicide, Hand weeding or pest control with light trap, Reduce the pesticide inputs, Reducing GHG emissions	0.48–1.85 t CO_2-eq ha^{-1}	Lei, 2013; Chen *et al*., 2016	Partial
Lowland conversion	Reduce emission Increase soil carbon Reduced use of agrochemical	14.9 Mt CO_2-eq ha^{-1}	ASEAN-CRN, 2023	Partial
Soil amendment -phosphogypsum and silicate fertilizer	Decreased seasonal CH_4 flux by 25–27 % in continuous irrigation, Decreased seasonal CH_4 flux 32–38 % in intermittent irrigations	**0.67 t** CO_2-eq ha^{-1}	Ali *et al*., 2013	Partial
Biochar	Decreased N_2O emissions by 36–40 % and 26–30 % under continuous and intermittent irrigations, respectively	7.24 to 8.43 t CO_2-eq ha^{-1}	Shin *et al*., 2017	Partial
Nutrient management	Reduce emission Increase soil carbon	0.26 to 0.55 t CO_2-eq ha^{-1}	DECCW NSW 2011	Partial
Water management	Reduces CH_4 emissions Saves water Saves energy	1.14 t CO_2-eq ha^{-1} yr^{1}	DECCW NSW 2011	Full
Drip Irrigation/efficient pump Solar-powered irrigation	Saves water Saves energy Reduces CH_4 emissions	1.502 t CO_2-eq ha^{-1}	Zhang *et al*., 2020	None
Water—saving irrigation strategy	Prevents the development of soil reductive conditions, Reduces CH_4 emissions	0.38–1.29 t CO_2-eq ha^{-1}	Ahn *et al*., 2014; Win *et al*., 2015; Xu *et al*., 2015	Partial

Adapted from Wang et al 2017, DECCW: Department of Environment, Climate Change, and Water NSW 2011 of sustainable production systems for the whole watershed, which allows intensification and diversification of the lowland production system and stabilizes improved production systems on the upland.

In rice cultivation, alternate wetting and drying (AWD) reduces water consumption and greenhouse gas (GHG) emissions.

Table 1 presents a list of low-carbon technologies associated with rice and their mitigation potentials which shows the impacts of the practices that help transform the low-carbon technologies into mitigation potential and desirable features of low-carbon technologies that should manifest in rice-producing plots and areas. In terms of the mitigation potentials, Biochar, zero-waste systems of farming, and fertilization in double rice-cropping systems recorded the highest mitigation potentials with 7.24 to 8.43 t CO_2-eq ha^{-1}, 6.1–11.1 t CO_2-eq ha^{-1}, and 4.1 t CO_2 eq ha^{-1} yr^{-1} respectively.

Table 2 provide the list of types of dissemination activities, locations and impacts of Sawah on yield of trainees.

Table 2: SAWAH dissemination activities since 2015

State	Description	Locations	No.Farmers Trained	AYBT T/Ha	YEAR	AYATT/ Ha
NIGER	ESTRASERIF	RANI	20	3.5	2015	5
NIGER	ESTRASERIF	UBANDOMA	25	3.5	2015	5
KOGI	ESTRASERIF	KORIKO, Sarkin Noma.	20	2.5	2015	4
NASARAWA	OJCB	MARABA,TUNDUN KAURI	8	3	2016	4.5
NASARAWA	OJCB	SHABU AZUBA,	25	2.2	2016	3
NIGER		GBAJIGI	24	3	2017	4
AKWA-IBOM	P P P	INI	21	-	2017	5
AKWA-IBOM	STATE GOVERNMENT	NUNG OBONG	31	2	2017	4
FCT	FADAMA	YABA	18	1.8	2017	4
KANO	SASAKAWA	BUNKURE, KURA	25	3.5	2017	4.2
KEBBI	ESTRASERIF	KAMBA	20	3	2017	5
KANO	ESTRASERIF	BAGWAI	20		2017	
BENUE	ESTRASERIF	Tse-Abata	20	3.2	2017	
KWARA	LAND MARK UIVERSITY	OMU-ARAN	10	2.1	2018	4
KATSINA	ESTRASERIF	AJIWA	20	3	2017	4.6
EBONYI	ESTRASERIF	UBURU	15	3.4	2017	4.5
NASARAWA	ESTRASERIF	ASAKIO	28	2.7	2017	3.5
KWARA	LAND MARK UIVERSITY	OMU-ARAN	12	2.5	2018	4
NIGER	ESTRASERIF	GBAJIGI	27	3	2017	4.3
BENUE	ESTRASERIF	APIR	20	3	2018	4.6
AKWA-IBOM	ESTRASERIF	IKOT ESEN	20	3.4	2018	4.5
ANAMBRA	ESTRASERIF	OGBOJI	20	2.7	2018	3.5
OSUN	ESTRASERIF	IWO	20	2.5	2018	4
OSUN	ESTRASERIF	OSOGBO, GBONMI	25	3	2018	5.5
TARABA	ESTRASERIF	MUTUM BIYU	25	3	2018	5.5
KWARA	ESTRASERIF	LAFIAGI	20	3	2019	5.5
KWARA	ESTRASERIF	SHONGA	35	3	2019	6
IMO	ESTRASERIF	MBAISE	25	3	2019	5.5
OYO	ESTRASERIF	IGBO ADAN	20	3	2019	6
OYO		PALAPALA	6	2.7	2019	5
SOKOTO	ESTRASERIF	GORONYO	25	3	2019	4.7
EKITI	ESTRASERIF	AISHEGBA,	25	3	2020	5
ABIA	ESTRASERIF	IBEKU	21	2.2	2020	4.5
NIGER	ESTRASERIF	SHESHIBEKUN	23	3.5	2020	6
OGUN	ESTRASERIF	IFASA, SAWONJO, IGBOGILA	20	3	2020	5.5
ONDO	ESTRASERIF	AWUJALE	25	3.2	2021	4.9
ONDO	ESTRASERIF	OKUTA ELERIN	25	3.3	2021	5.3
ONDO	ESTRASERIF	AKURE NORTH SECRETARIATE	25	3.0	2021	5.0
ENUGU	ESTRASERIF	NNEWE	25	2.7	2021	4.5
BENUE	ESTRASERIF	MAKURDI	25	3.2	2021	5.6

Note: AYBT=Average Yield Before Training, AYAT=Average Yield After Training, Expansion strategy for Sawah Eco Technology for rice farming- EXTRASERIF, On the job capacity Building – OJCB, PPP- private public partnership

DISCUSSION

From Figure 3, Sawah-based rice production development in Nigeria started in selected three villages with 0.1 ha in total area in 2001. The establishment of a demonstration field (1.0 ha) at Ejeti village, Niger State in 2002 stimulated the project. The typologies of the Sawah techniques were based on sources of water such that rain-fed Sawah receives only rainwater and no irrigation water flow to the plots; while spring type receives water from springs that flow into the field when rainfall ceased, and pond type that receives water through supplemental irrigation with a pumping machine from an artificial pond in the field. Dossou-Yovo *et al.* (2022) stated that rice production in both irrigated and rainfed lowlands enhances sustainable rice intensification, application of alternate wetting and drying techniques, reduction in water use, the establishment of water control structures, deployment of Sawah rice production technique, and the implementation of smart-valleys approach for land and water development.

As presented in Figure 4, Sawah rice production technology explored the principles underlying the practice of alternate wetting and drying methods of rice production (Suwanmaneepong *et al.*, 2023; Oladele *et al.*, 2019), practicable in lowland rice-growing areas where soils can be drained in 5-day intervals (Richards and Sander, 2014), and a technique where the plot is allowed to dry between successive irrigation (Cabangon *et al.*, 2014). This system and practice reduce the amount of irrigation water input by as much as 35% without yield loss, meet the required amount needed for evapotranspiration, seepage, percolation during the crop growth period, promote effective tillering and root growth, reduces irrigation and labour costs, improved soil stability at harvest and allow mechanical harvesting (Tuong and Bhuiyan, 1999; Nalley *et al.*, 2014; Vial, 2005; Van der Hoek *et al.* (2001).

Tong *et al.* (2017) posited that effective control of irrigation, pesticide, and fertilizer use would mitigate greenhouse gas (GHG) mitigation in rice production. Water regime change in rice through mid-season drainage and moist intermittent irrigation conditions reduces CH_4 emissions, while enhancing N_2O emissions (Chen *et al.*, 2021). However, CH_4 emissions could not be completely eliminated (Feng *et al.*, 2021), thus the need for low-carbon technologies which can effectively mitigate global warming through the decarbonization of farmers' practices (Scarlat *et al.*, 2015). Low-carbon agricultural management practices have been recommended to address and mitigate the negative impact on agricultural-related activities and promote the sustainable development of agriculture (Huang, 2022). Current research on low-technologies has been on the evaluation of low-carbon agricultural production and promotion of low-carbon agricultural techniques such as soil testing formula fertilizer, straw returning and biological pesticide, and intermittent irrigation (Li *et al.*, 2021). The prevalence of the circumstantial need for "carbon peak and carbon neutralization", requires low-carbon rice technology that can effectively reduce fossil fuel consumption during mechanical operations, reduced pesticide and chemical fertilizer use, increase soil organic carbon and nitrogen, to effectively decrease GHGs in paddy field. Agricultural low-carbon technologies are a collection of technologies that can reduce carbon emissions along the value chain (Vinholis *et al.*, 2021; Xiong *et al.*, 2021); increase soil carbon sequestration (Cooper *et al.*, 2021); achieve negative emissions from crop production (Liu and Feng, 2021) decouple agricultural economic growth from CO_2 emissions (Mao *et al.*, 2021).

Sawah rice production techniques have some of the features of the low-carbon technologies listed in Table 1. The full features exhibited by Sawah are planting green manure in the fallow season, water management, alter-

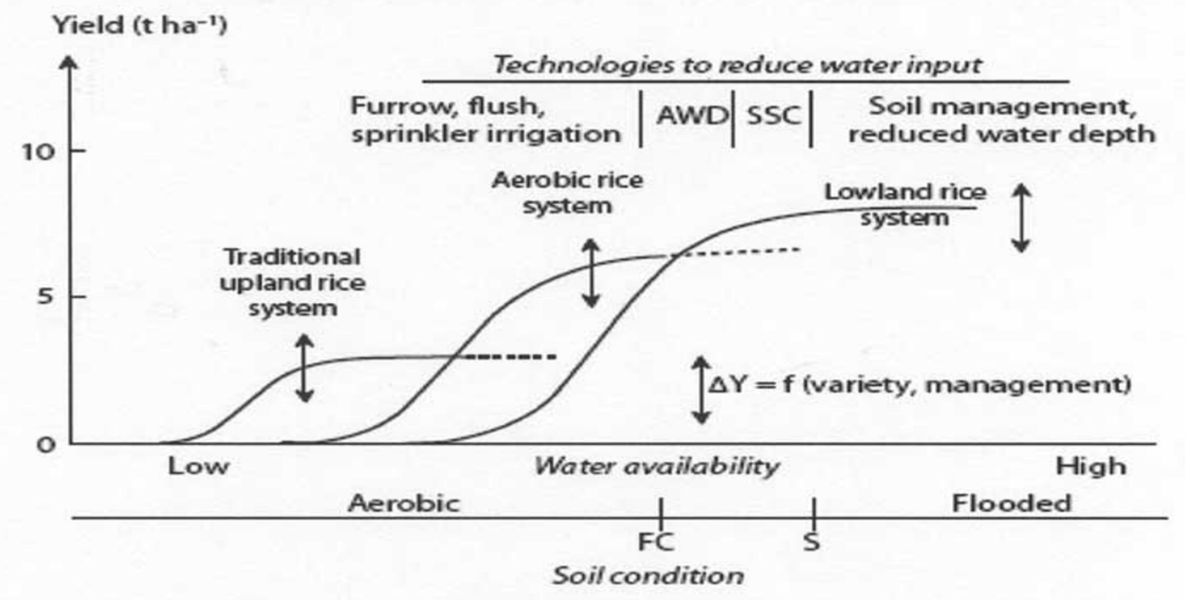

Figure 5: Schematic presentation of yield responses to water availability and soil condition in different rice production systems and their respective technologies to reduce water inputs. AWD = alternate wetting and drying, SSC = saturated soil culture, FC = field capacity, S = saturation point, Y = change in yield. Adapted from Cabangon et al. (2014) and Tuong et al. (2005)

nate wetting and drying, system of rice intensification, and optimizing fertilizer management. Wakatsuki *et al.* (2009) reported the use of Sawah plots for planting green manure and cover crops during fallow periods especially when the water source is not perennial. Oladele and Wakatsuki (2010) reported that Sawah rice technology improves nitrogen fixation by soil microbes and algae, enhances effective water control and management, soil organic matter, fertilizer efficiency, weed growth suppression, and the immune mechanism of rice plants. Wakatsuki *et al.* (2009); Alarima *et al.* (2011) and Nwite *et al.* (2013) noted Sawah technology enhances *Systems of Rice Intensification* (SRI), development of sustainable production systems, diversification of the lowland production system by positively influencing the soil organic carbon, total nitrogen, cation exchange capacity, and available phosphorous.

From the list of low carbon technologies provided in Table 1, Sawah rice production techniques overlaps with several practices that inherently promotes low-carbon agriculture. Nan *et al.* (2020) stated that adaptable low carbon technology for rice fields reduce GHG emissions, lead to high economic benefits, and compatible with farmers' farming preferences.

Dissemination pathways of low-carbon technologies through Sawah rice production technology

Agricultural extension services as a common denominator for agricultural development is highly dependent on the competencies of extension agents who carry out the tasks. Agricultural extension primarily disseminates technologies through several pathways in order to modify the attitude, knowledge, and skills of the end users, which in this case are rice farmers. The scaling of low-carbon technologies inherent in Sawah rice production technique would lead to the maximization of the benefits of low-carbon agriculture technologies in mitigating the effects of climate change and reducing emissions associated with rice production. The following sections describes dissemination pathways used by for Sawah rice production technique, namely: On-farm demonstrations and field days, Farmer to farmer and Expansion strategy for Sawah Eco-Technology for rice farming (EXTRASERIF).

On-farm demonstrations and field days

The introduction of Sawah rice production technology can be attributed to the initial research activities on lowlands characterization and on-farm demonstration based on a collaboration of several Japanese Institutions, universities, and Watershed Initiative in Nigeria (2001), a Non-Governmental Organization, together with National Cereals Research Institute (NCRI) and agricultural extension agencies. The Sawah rice production technology involves bunding, inlet, and outlet connecting irrigation and drainage, ploughing using power tiller, flooding (10 cm water level), puddling, leveling, smoothing, transplanting, use of improved variety (Wita 4), and controlled fertilizer application. The intervention activities combined with research relied principally on on-farm demonstration and farmers field days. The on-farm demonstrations illustrate the practical steps in the use of Sawah technique within the farmers' field in order to allow for comparative observation through action research orientation.

Some form of experimental designs is introduced to control for variances and to provide opportunity for the involvement and experiential learning among farmers, extension officers, development workers, input dealers among others. This approach ensured that research and extension systems are synchronised in the farmers' world and vicinity. Field day is an extension educational method that creates opportunities for farmers to share information, observe the adoption and performance of agricultural technology, and deliberate on technological attributes. Field days may be organised in conjunction with other actors in the agricultural value chain and can be more than one day event. Field days advance and increase the adoption among farmers as a cost-effective as diffusion mechanisms, through practical learning and pragmatic experiences acquired form the interaction and field observation sessions, which have mad on farm demonstration and field days are the most preferred technology transfer methods among development workers. Practical sessions of on-farm demonstrations and field days have been the hallmark of dissemination of Sawah techniques since inception.

Farmer- to-farmer

The application of on-farm demonstrations and field days for dissemination of Sawah technology led to the mastery of the technology by rice farmers in many locations within the country. This led to the use of farmer-to farmer extension approach to reach more farmers. The immediate impact on yield was primary and the low-carbon was secondary thus, lead farmers, master trainers among farmers were used to train other farmers as the demand for the acquisition of the skill was increasing. Farmer-to-farmer extension (F2FE) can be described as the delivery of training by farmers to farmers, which include training activities by Model- farmer, farmer-promoter, lead farmer, community knowledge worker and farmer-trainer among other semantic applications of the generic meaning. Farmer- to farmer extension has been very proactive in coping with the low extension agent ratio to farmers, which often reduce the reach of extension services to farmers, particularly women farmers.

The Farmer- to farmer extension approach has also provided diffusion of existing practices and improving farmers' capacities. Farmer- to farmer extension has been very complementary to formal extension services particularly in the advent of pluralistic extension services. Farmers from communities adopting Sawah technique were sometimes commissioned and supported to conduct training, while in other cases neighbouring communities requested for such training from their colleagues.

Expansion strategy for Sawah Eco Technology for rice farming (EXTRASERIF)

The intervention of Sawah activities and the use of power tiller for some activities in the on-farm demonstrations and field days propelled the involvement of National Centre for Agricultural Mechanization (NCAM) into the hub of Sawah activities. NCAM eventually became the institutional mechanism to reach farmers, government, policy makers and non-government organizations for the promotion of Sawah technology due to its national mandate on agricultural mechanization. At this stage consistent results from on-farm demonstrations and field days have been established and resources and partnership were sought for the expansion of the Sawah technique due to ageing and low funding of the Japanese leader of the project. Expansion strategy for Sawah Eco Technology for rice farming- (EXTRASERIF) is a collaborative efforts where established Sawah rice practitioners mainly affliated with NCAM deploy on-farm demonstrations and field days activities in different parts of Nigeria, through directed support and resources of different organizations in Nigeria. This has helped the Sawah team to train several farmers, extension agents and other agricultural personnel in the implementation of Sawah. The Guardian (2021) reported EXTRASERIF activities for Ogun State (South West Nigeria), while Headliner (2020) reported that rice growing farmers' Cooperative Societies members that participated in the EXTRASERIF activities in Abia State recorded yields of 6 ton ha^{-1}. Similarly, Landmark University (2018) reported a collaboration with EXTRASERIF team of National Centre for Agricultural Mechanization (NCAM) on for university students, staff and neighbouring rice communities. A World Bank programme on effective utilisation of lowland also partnered on EXTRASERIF to train rice farmers (Blueprint, 2017).

CONCLUSION

The irrigated lowland rice production is notable for greenhouse gas (GHG) and generates four times the GHG emissions per ton of crop as wheat or maize, in the form of methane and nitrous oxide because flooding rice fields blocks oxygen penetration into the soil, and allows methane-producing bacteria to thrive. Consequently, in order to ensure food security and mitigate the negative impact on agricultural-related activities, and promote sustainable development, low-carbon agricultural management practices have been recommended. Sawah rice production technology has been developed and disseminated using several pathways such as On-farm demonstrations and field days, Farmer- to farmer, and Expansion strategy for Sawah Eco-Technology for rice farming; but have unwittingly promoted low-carbon technology adoption among farmers. The features of sawah technology practices, and the recommended low-carbon technology overlaps in many areas in completely or partially. It is therefore to be intentional about the promotion of sawah technology in order to achieve sustainable rice production with high yields and conjointly mitigate climate change.

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