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Assessing Suitability of Irrigation Scheduling Decision Support Systems for Lowland Rice Farmers in Sub-Saharan Africa—A Review

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Abstract

Irrigation in lowland rice production systems in Sub-Saharan Africa (SSA) is mainly based on traditional surface irrigation methods with continuous flooding practices. This irrigation method ends up using a lot more water that would have otherwise been used to open more land and be used in other water-requiring sectors. Various studies suggest Alternate Wetting and Drying (AWD) as an alternative practice for water management that reduces water use without significantly affecting yield. However, this practice has not been well adopted by the farmers despite its significant benefits of reduced total water use. Improving the adoption of AWD using irrigation Decision Support Systems (DSSs) helps the farmer on two fronts; to know "how much water to apply" and "when to irrigate", which is very critical in maximizing productivity. This paper reviews the applicability of DSSs using AWD in lowland rice production systems in Sub-Saharan Africa.

Keywords

Lowland Rice, Irrigation Scheduling, Forecasting, Decision Support Systems, Rice Production, Farmer-Led Irrigation, AWD

1. Introduction

One of the effective ways to improve irrigation scheduling is by combining water-saving practices in rice with Decision Support Systems (DSSs) [1] [2] [3] [4] describe a DSS as a computerized system for assists decision-making process that integrates modeling, databases tools, and sometimes through the internet, to analyze and rank a set of alternatives. "Supporting a decision" means helping decision-makers to generate alternatives, rank them, and make appropriate choices

[5]. Studies from around the world [1] [2] [3] [5]-[11] show that the use of DSSs contributes to improved planning of farm activities and improved irrigation water production. Interactive DSSs through smartphones/tablets can play a pivotal role in translating soil and geographic information into field-specific management practices [12]. Furthermore, DSSs can be integrated into weather forecasting tools to mitigate the negative impacts of weather changes and climate change on farms [13]. The ability to predict climate has improved in recent years with various online sources generating weather forecast data obtainable through Application Programming Interfaces (APIs). These online weather data sources use atmospheric models in predicting the weather. They include Aemet (7-day forecast), metoffice (5-day forecast), met.no (10-day forecast), openweathermap (5-day forecast), weatherbit (5-day forecast), darksky (7-day forecast), wunderground (10-day forecast) and apixu (10-day forecast) [14]. They are differentiated by the degree of accuracy and the length of the forecast horizon. Integrating these APIs into DSSs improves their forecasting abilities, and offers meteorological data in historical, real-time, and forecast forms, hence improving the knowledge of scheduling and analysis of water requirements for irrigation system performance [15] [16]. This paper acknowledges the low penetration of irrigation scheduling DSSs in SSA and the low integration of these systems with the known lowland rice irrigation water-saving strategies like AWD. However, this is mainly accelerated by the limitations in the rice production system in SSA.

2. Rice Production in Sub-Saharan Africa

To adequately feed more than 9 billion people by 2050, the world must close nearly a 70% gap between the amount of food currently produced and that needed by 2050 with less irrigation water use [17] [18] [19]. This urgently gives rise to the need for production increments with less water usage. Rice has become both a major food security crop and a cash crop globally and specifically in several countries in Sub-Saharan Africa (SSA) [20] to the extent that, achieving self-sufficiency for rice through enhanced rice production is prominent on the agenda of many SSA governments. SSA has the lowest cereal self-sufficiency ratio and the largest projected population growth rate among the (sub) continents, producing about 60% of rice consumption [21]. This brings a challenge in meeting the demand for rice supply, a staple food. In addition, improving agricultural productivity to keep pace with the fast-growing food demand is a huge challenge for Sub-Saharan Africa [22]. In general, [20] indicates rice production (milled equivalent) for SSA is 22.81 million tons against consumption of 34.83 million tons [20]. In addition, rice consumption in SSA increased by 81% from 2008 to 2018 with a corresponding production increase of 55% [20]. The Food and Agriculture Organization (FAO) of the United Nation's Prevalence of Undernourishment (PoU) indicator shows Africa is not on track to meet the food security and nutrition targets of Sustainable Development Goal 2. After a long period of improvement between 2000 and 2013, hunger levels have substantially worsened and most of this deterioration occurred between 2019 and 2020. For example, in 2020, about 281.6 million Africans were undernourished, an increase of 89.1 million over 2014 [20]. Studies [23]-[27] agree that the rice demand in SSA has been on the increase to the extent that the demand cannot be met by the current levels of production. This has continuously pushed the expansion of the area under rice crop farming in SSA, most especially in low-land rice [28]. However, at the field level, low-land rice receives up to 2-3 times more water than other irrigated crops [29] due to the use of CF system that requires a huge quantity of water as compared to other irrigation water application techniques [30] [31]. CF is thus being confronted by the declining global water resources [32] and increasing population, hence the need to grow more rice with less water. Considering that the global fresh water resources are becoming scarcer and agriculture is increasingly becoming water stressed, farmers are exposed to the drought effects, and the stiff competition from other sectors mainly urban and industrial, for fresh water resources [4] [33]. In the recent past, the declining water supply affected nearly four billion people throughout the world [34] and this is not about to recede. It is estimated that by 2025, about 20% of rice irrigated areas are expected to experience "physical water scarcity" while 29% may suffer from the "economic water scarcity" [35]. While the use of efficient irrigation systems by lowland rice farming communities is highly desired, it alone is not enough [1] [36]. A recent study by [37] on the irrigation of wheat, rice, sugarcane, berseem, sorghum and maize in Pakistan revealed that about 60% of irrigation water is lost through over irrigation and this is mainly caused by lack of farmers' knowledge about irrigation scheduling. Regardless of the irrigation method used, appropriate irrigation scheduling has long been known to help farmers apply water appropriately [38]. To improve water use efficiency, SSA lowland rice farmers must improve irrigation water management through adoption of water-saving practices with proper irrigation scheduling [15] aided by Decision Support Systems.

3. Limitations in a Sub-Saharan Africa Lowland Rice Production System

In the SSA context, rice farming is broadly categorized into two typologies: lowland and upland. Defined respectively as cultivated fields with or without standing water in the fields during growth, lowland is the most common rice farming system in SSA under Continuous Flooding (CF) [25] and hence will be the focus of this paper. While there are several limitations to the adoption of the water-saving DSSs in SSA, the following are specifically the most limiting.

3.1. Farmers' Low Literacy Levels

Rice in SSA is predominantly grown by smallholder farmers with low education levels to the extent that they require simplified Graphical User Interfaces (GUIs) in DSSs to ease their adoption. As studied by [25], 90% of SSA rice farmers whose primary economic activity is crop farming has a junior high school education or less. Such farmers may not easily adopt the DSSs technologies especially if the user interface is not designed to be farmer friendly [39] [40]. The farmer friendliness of a DSS thus revolves around two attributes: Firstly; the Graphical User Interface (GUI) should be designed with utmost simplicity for amateur users to pick needed information, preferably through a mobile phone application; otherwise, the GUI remains technical. GUIs should be clear of computation process displays because such information may confuse farmers and how they translate the information into usable chunks [7]. Secondly, such a DSS should require minimum data input by farmers. While initial data for set up may be required on manual input, the DSS should automatically capture subsequent inputs required to generate irrigation schedules given that farmers may not accurately access, decipher and input appropriate parameters.

3.2. Farming in Small Plots

A typical SSA lowland rice production system is characterized by small-scale irrigation schemes where over 96% of individual smallholder farmers operate on small plots of less than five hectares [20] [41] taking both operative and strategic decisions at their farms. This type of farmer-led lowland rice irrigation (usually labelled "informal") takes up the lion's share of the irrigation water use in SSA [42], albeit not usually captured in official statistics [43]. It collectively occupies the biggest portion of the irrigated area with high unnoticed water footprint [44]. Most current irrigation DSS are designed to operate at scheme level, and this may not accommodate the highly segmented nature of farmers' parcels. It is crucial that the DSS technology solutions be farmer-centric down to the individual farmer in this kind of segmented farming system.

3.3. The Use of Continuous Flooding Method of Irrigation

Traditionally, lowland rice is grown in leveled fields that are continuously flooded throughout the growing season, until up to 7 to 10 days just before the pre-harvest drainage [34] [45]. Even though these fields operate at below 50% water use efficiency mainly due to limited water-saving practices used [46], the farmers are so comfortable with CF that any attempts to advise them to use other water-saving methods is met with resistance. CF is so easy to apply to the extent that farmers have not to remember anything else but keep the fields flooded with about 5 - 10 cm of ponded water, keeping rice under anaerobic conditions [47] [48]. Any water-saving DSS designed to be used by these farmers should be easy to use, with straight forward but convincing irrigation decisions in the farmers' context.

3.4. Limited but Promising Smart Phone Connectivity

While the ability of Information and Communication Technologies (ICTs) to predict, process, simplify and relay complex farming information and scenarios has improved in recent years, SSA still has limited connectivity to smart phones [13]. While 40% of the adult SSA population is now connected to mobile internet services [49], overall internet usage remain at 40% [50] with smartphone users at 49% of the population. However, this is promising considering the 82% SIM connection penetration rate in the region with over 917 million users in 2021 projected to 1.09 billion users by 2025 [49]. This low smart phone coverage limits access to internet solutions including the DSSs

3.5. Limited Access to Information

Despite the increased mobile phone penetration rate in SSA, the region still remain with limited access to computerised DSSs most of which have largely remained desktop-based [51]. Some advances in ICT solutions come with user licence fees which restricts access to the extent that farmers may not easily see the need of paying for and hence adopting such solutions. Creating free-access farmer friendly DSS or with low subscription fees could improve access thereby helping farmers to adopt good water management practices. On the other hand, there is generally limited access to improved knowledge in rice cultivation [41] and to information by the farming communities in SSA on improved farming and water-saving practices [52]. While the rainfall forecast by regions in most African countries is given monthly, the farmers are unable to make any use of it. Other weather parameters are not accessible, and, in most cases, public weather stations are tightly controlled, data is for sale and farmers are not willing to pay the price. However, those who manage to access, are unable to do any data processing and analysis to make use of the information. With more than 70% of farmers taking the driving seat to improve their agricultural water use by investing in and developing new farmer-led initiatives [53] [54], the absence of usable information denies them a chance to align their initiatives to sustainable practices.

4. Lowland Rice Water-Saving Practices

Over the past 20 years, efforts around the world to reduce rice water footprint have yielded practices that improve water management in rice production [33]. The studies [29] [35] [55] [56] [57], successively agree that rice can be grown with less water if better water management practices are adopted. Among the water management practices that have been studied and practiced in lowland rice production systems, Alternate Wetting and Drying (AWD), and AWD based System of Rice Intensification (SRI) [58] have been found to reduce rice water intake without significant yield loss.

4.1. Alternate Wetting and Drying

Under Alternate Wetting and Drying (AWD) practice, rice fields receive alternate cycles of saturated and unsaturated conditions. In this practice, irrigation is interrupted for days, and water is allowed to subside until the soil reaches a moisture threshold, after which the field is re-flooded to saturation. To carefully manage irrigation, various studies give varying ways to measure AWD thresholds, but, Field Water Level (FWL) measurement is one of the most common and is easily quantifiable [47] [58] [59] put forward "safe AWD" guidelines crucially indicating that water level threshold should not be allowed to drop more than 15 cm below the soil surface (FWL ≤ 15 cm) during these AWD alternate cycles. However, short saturation periods of 5 cm above ground are required to be maintained during critical development stages of rice crop to mitigate water stress that would potentially lead to severe yield reduction. The critical stages are: 1) two weeks after transplanting and 2) flowering, from one week before to one week after the peak of flowering during heading if yield is to be maintained or even increased. All in all, the duration taken to achieve these alternate cycles vary depending on the stage of crop, weather, and soil type [60]. "Safe AWD" potentially reduces water inputs by about 30%, without change in yield as compared to CF [61]. In addition, a study by [62] revealed that AWD stimulated a deeper root system making the plants more water stress tolerant hence increasing the Water Use Efficiency (WUE) to 18.66 - 18.79 kg/ha/mm in AWD as compared to 11.95 - 12.19 kg/ha/mm in CF (**Figure 2**). Farmers especially those with scarce water resources already are inadvertently applying some kind of AWD to save on irrigation water pumping costs [63]. AWD is also economically rated as a viable irrigation practice that having a potential of increasing yield, saving water, labour, and fuel consumption with minimal harm to the climate [55].

4.2. AWD in the System of Rice Intensification

The System of Rice Intensification (SRI) is a lowland rice farming practice aimed at increasing the yield of rice produced with low water usage through application of AWD together with agronomic changes that include transplanting younger seedlings singly spaced [64]. Studies [62] [64] [65] agree, that SRI gives good agronomic and economic savings than Continuous Flooding practice as shown in **Table 1** resulting from making certain agronomic changes in conventional rice-growing practices. Considering that in general, most farmers in SSA face limited economical and physical access to improved agro-inputs [66], the use of AWD SRI reduces the quantity of seed required per ha from 120 to 10 kg/ha (**Table 1**), hence lowering overall input cost to the farmer. Furthermore, on-farm evaluations of impacts from AWD SRI Methods conducted in eight main rice growing countries (Bangladesh, Cambodia, China, India, Indonesia, Nepal, Sri Lanka and Vietnam) indicate that AWD SRI increases yield by 47%, saves 40%

Table 1. Comparison of major agronomic practices for SRI and for conventional irrigated rice. Source: [67].

	Seed requirement (kg/ha)	Transplanting age (days)	Transplants per clump
AWD SRI	5 - 10	8 - 15	1
Conventional	80 - 120	20 - 30	3 - 4

water, increases income per hectare by 68% and reduces per hectare costs by 23% [65].

4.3. The Use of AWD in DSS

To sum it up, a number of studies [29] [30] [32] [34] [35] [57] [58] [68] have widely studied and highly recommended the adoption of AWD and AWD based SRI, by rice growers to reduce the rice water footprint. Despite these recommendations, farmers have remained on the traditional CF farming practice. Increased efforts are needed to scale out large scale adoption of AWD by the rice growers) [29]. The irrigation threshold for safe AWD varies with soil type, crop growth stage and weather [69]. These may pose a challenge for farmers to keep track of the optimum irrigation threshold variations. DSS provide the opportunity to the farmer to monitor these irrigation thresholds accurately and remotely [70].

5. The Evaluation of DSSs for Lowland Rice Production

A number of DSSs have been developed targeting management aspects in horticulture [71], fertilizer management [22] [72], and to some extent for use in lowland rice production [73]. Selections of the DSS that accommodate functionality in lowland rice production are evaluated in **Table 2**. The evaluation in Sections 5.1 - 5.4 focused on AWD capabilities, simplified or technical DSS GUI, the nature of data input required in the DSS, the real-time and forecasting capabilities and the ease of access of the DSS by farmers.

5.1. The FAO Cropwat

CROPWAT, is a DSS that was developed by the Land and Water Division of the Food and Agriculture Organization (FAO) of the United Nations [2]. The FAO CROPWAT model applies the FAO Penman-Monteith equation and crop coefficients modeling (**Figure 1**) to estimate the crop evapotranspiration and yield

Table 2. Selected irrigation DSS in Africa and globally.

IDSS	Locality	AWD	GUI	Input	Real-time	Forecast	Access	Source
WIDSS	Asia	Yes	Simplified	API feed	Yes	Yes	N/A	[74]
SIMIS	Global	Yes	Technical	Manual	Yes	Yes	N/A	[75]
Web Paddy GIS	Global	No	Simplified	Manual	No	No	Free	[40]
CropWat	Global	Yes	Technical	Manual	No	No	Free	[76]
AquaCrop	Global	Yes	Technical	Manual	No	No	Free	[77]
SRDSS	Global	No	Technical	Manual	No	No	Free	[78]
GIS-based DSS	Africa	No	Technical	Manual	No	No	Free	[79]
Rice Crop Manager	Africa	Yes	Simplified	Manual	No	No	Free	[22]
MIKEHydro Basin	Africa	Yes	Simplified	Manual	Yes	No	Free	[46]

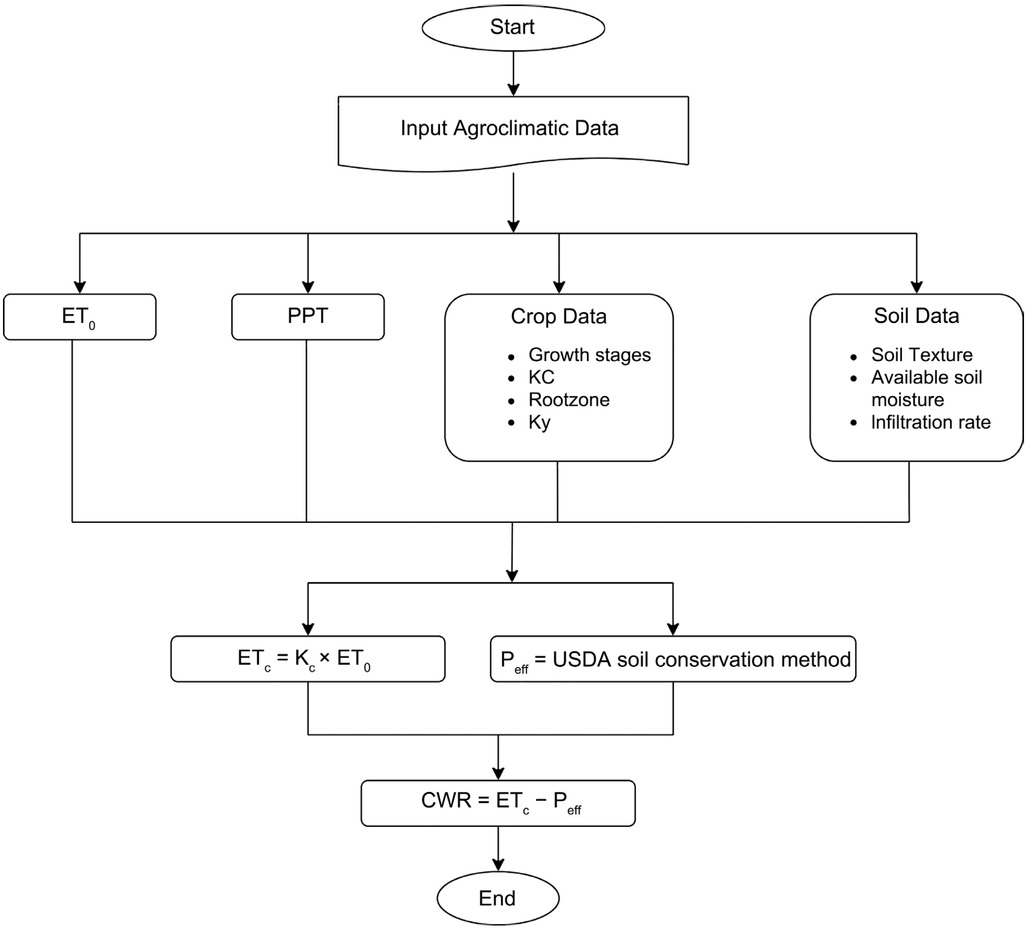

Figure 1. CROPWAT flow diagram. Adapted from [81].

response respectively for different irrigation strategies in different soils [80]. The program is used to calculate the crop water requirements [81] (**Figure 1**), irrigation requirements of rice and irrigation schedules at different levels including AWD for different management conditions and the calculation of scheme water supply for varying crop patterns. CROPWAT 8.0 can also be used to evaluate farmers' irrigation practices, develop irrigation schedules and to estimate crop performance under both rainfed and irrigated conditions. FAO CROPWAT is widely applied by technical users [82] [83] a reason that could define its technical data-hungry graphical user interface, wide application in DSS engines and limited or no application by the smallholder rice farmers in the SSA rice production systems.

The amount of data entry and adjustment points required in the Evapotranspiration (ETo), rainfall, crop and soil environments, and the technical display make the software more suitable for technical users than SSA rice farmers described earlier in Section 3 of this paper. CROPWAT software is robust and has free access to download on the internet, it relies on manual data input either directly or imported through CLIMWAT 2.0 Climate data for the period (1971-2000). It is evident from (**Figure 1**) that CROPWAT does not forecast nor is it real-time and does not relay irrigation schedules to farmers' mobile phones.

5.2. FAO AquaCrop

The FAO AquaCrop model has remained a key reference for estimating crop yield response to water and irrigation scheduling [77] [84] [85] [86]. The FAO AquaCrop model has been widely assessed [42] [87] [88] [89], calibrated [86] [87] [90] [91] [92] and validated [91] [92] [93] [94], in various field experiments. The AquaCrop model represents a deliberate effort to incorporate current knowledge of crop physiological responses into a tool that has crop yield prediction capabilities based on the water supply available.

Represented by the flow chat in Figure 2, the model creates a robust tool that can compare the predictable against actual yields in different scales at farm level and regional level to identify the constraints limiting crop production and water productivity. The FAO AquaCrop GUI comes in a highly technical desktop package and is complicated for direct use by farmers in SSA who have limited access to desktops and low literacy levels to input and interpret the results. It has rather seen much application in DSS engines [2] [6] [72] [80] [84] [90] [96] [97]

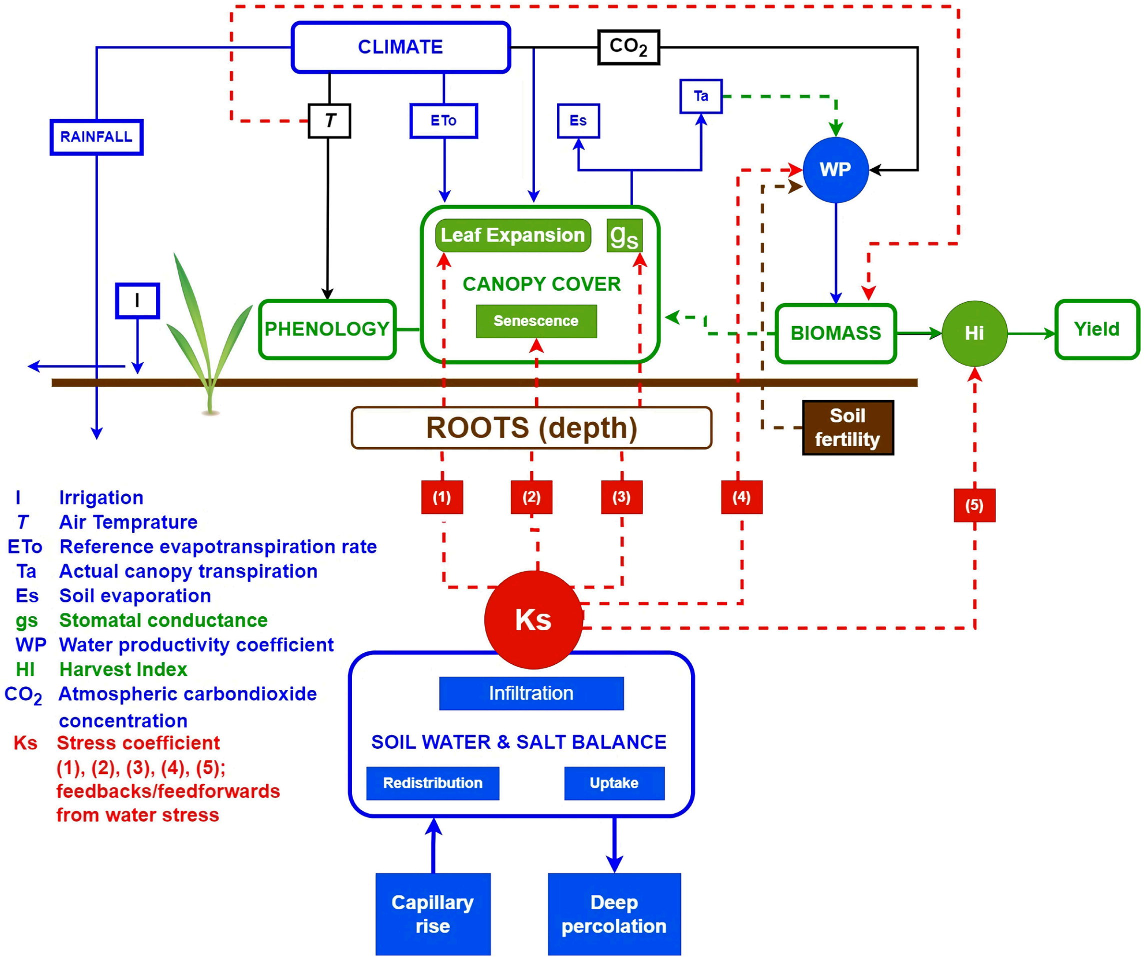

Figure 2. AquaCrop flow diagram. Adapted from [95].

as a model for irrigation scheduling, water use efficiency and water productivity. AquaCrop is more of scenario modeling, planning and benchmarking tool for planners and technical users.

5.3. Web-Based Irrigation Decision Support System

Another set of DSSs more focused on overall scheme canal management and distribution is the Web-based Irrigation Decision Support System (WIDSS) [98]. It is a sophisticated DSS that supports most farming aspects in today's production systems by finding patterns and trends from large volumes of data that can be used in predicting future actions and their impacts [97]. WIDSS is designed for canal irrigation management in large-irrigated districts. It is a real-time web- and sensor-based irrigation DSS designed for large scale canal irrigation management based on water balance method to provide 10 days forecast of canal irrigation water requirements. It uses simulations of daily field water balance, evapotranspiration, and precipitation (**Figure 3**). The water balance simulation forecasts the required water to be supplied by the canal. The user has a choice to switch between irrigation schedules and sensor feedback deliver end user confirmation if the irrigation water is applied. Input data updates automatically from in-field monitoring stations, the database of the meteorological station, and

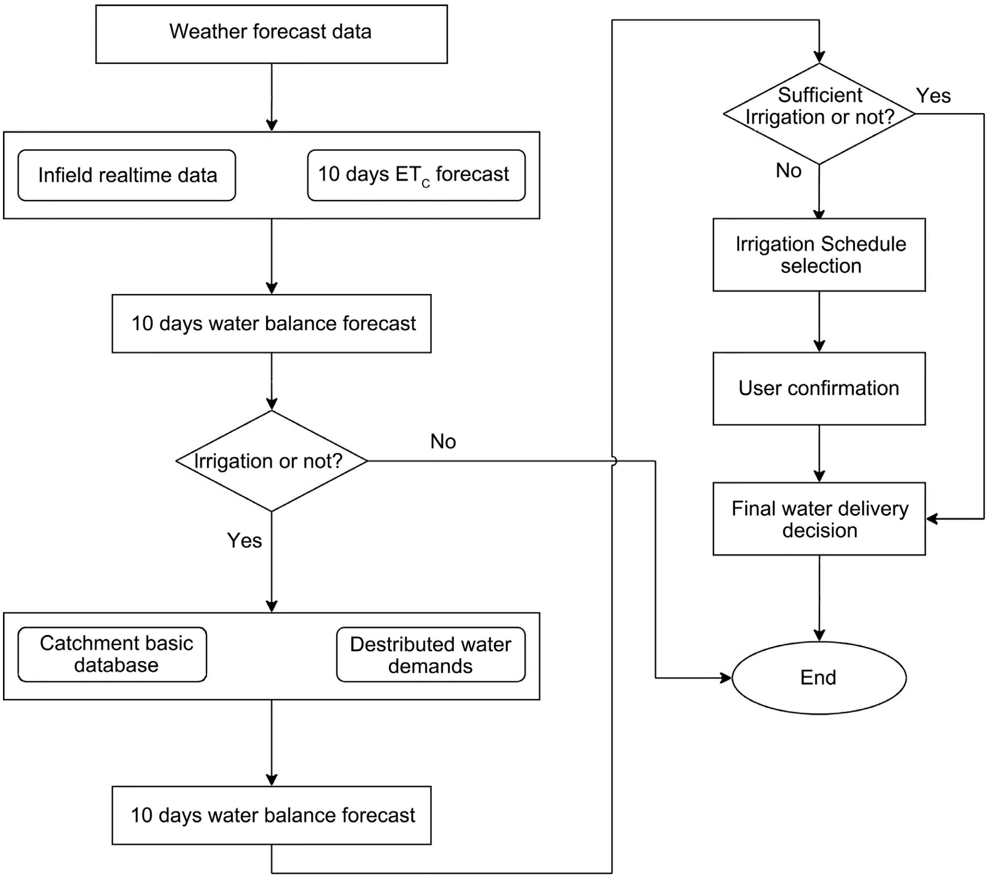

Figure 3. WIDSS flow diagram. Adapted from [74].

the public weather forecast website. This makes the operation easier and more intelligible [74]. A web-based version provides in-field data displayed with geographic information, makes upgrades more convenient, and allows end users to easily access the system at any place with Internet access. In a field experiment, WIDSS used twenty in-field monitoring stations that were constructed in the study. These included three soil moisture monitors, four paddy water level monitors, three pond water table monitors, one groundwater table monitor, and nine canal water level monitors. These were powered by sensors and solar power using GPRS wireless communication network as the data transmission channel to provide hourly, real-time, in-field data to support irrigation decisions. Despite the DSS having a farmer-friendly GUI, real-time irrigation scheduling, 10-day forecast and automatic data input from both sensor and APIs, only a desktop version was developed albeit still undergoing development and only accessible in Southern China [74].

5.4. Scheme Irrigation Management Information System

Scheme Irrigation Management Information System (SIMIS) [75] on the other hand is an irrigation DSS used either as a management or a training tool in irrigation schemes. The data needed for the technical and administrative management of the scheme can be stored, edited, and displayed in various forms. SIMIS performs the technical irrigation network designs, water distribution scenarios and schedules using CROPWAT model. It has got several functions in cannal management including real-time canal irrigation water forecast, dynamic water allocation decision and irrigation information management. Developed for irrigation system managers, the GUI is too technical for farmers to directly use the system and farmers can hardly input and interprete the data out of the system.

5.5. Other DSSs

- More advances in DSSs development include; **SRDSS** [78] a spatial rice decision support system that primarily helps researchers, managers and planners to evaluate optimum rice sowing dates, management practices and yield for a set target yield in different locations. Geographic Information Systems (GISs) have been used to develop DSS for canal and distributary irrigation water demand estimation have been developed to operate in real-time [99]. Considering that most DSS use models which require calibration and validation, new developers have begun using direct formula to develop DSS for lowland rice using short-term weather forecast APIs [100]. The global advancement of DSS as has been extensively reviewed by [4] [6] [9] as well as widely studied by others [10] [42] [101], has brought about notable water savings and production increases in lowland rice production.
- **Web Paddy GIS** is a precision farmer irrigation DSS that is built to solve issues around portability, accessibility and affordability of DSS by the farmers, who include semi-literate farmers in rice production systems in developing

countries [40]. It was developed incorporating most farm decision aspects including decision support on irrigation, yield monitoring, and soil integrated with ArcGIS and Visual Basic powered "Precision Farmer" system [40]. Web Paddy GIS uses open-source codes and thus requires no licence fees on usage and information sharing. Considering that most DSSs use commercial software, Web Paddy GIS has provided an opportunity to share open-source web-based GIS between farm managers and researchers at no cost.

- In SSA specifically, **Rice Crop Manager** (web-based DSS) and its counterpart **Rice Advice** (android application) are two twin DSSs developed by the International Rice Research Institute (IRRI) and Africa Rice Centre for rice crop management [102]. They are cloud-based and provide farmers in SSA with field-specific nutrient management forecast regarding when, how much, and what kind of fertilizer to apply [73]. Farmers give feedback in the system through survey questions and focus group discussions, regarding various aspects including rice variety, irrigation water availability, fertilizer use, agroecological zone [102]. Using this feedback, the recommendations are computed and availed to farmers at no cost. Currently, these two DSSs provide free guidelines on crop and nutrient management practices at both the beginning and during the season; they are however not yet focusing on irrigation scheduling especially for lowland rice farming.
- Some efforts have been directed towards integrating GIS in DSSs to develop more GIS-based DSSs and Remote Sensing (RS) for SSA. Such a system is **MIKEHydro** Basin is an irrigation DSS developed to mitigate problems that arise from sharing and allocating water in a scheme canal optimally, equally, and promptly in accordance with the irrigation schemes [79]. The DSS helps to remotely identify potential sites for setting up Rainwater Harvesting (RWH) technologies for rice farming communities in Tanzania. This DSS like others in existence has not yet integrated AWD and other attributes that enhance easy adoption by the SSA smallholder rice farmers.

6. Lessons Learned and Future Perspectives

The Decision Support Systems (DSSs) if well applied can help farmers to monitor field water availability and irrigation thresholds of various irrigation water management practices [60] while reducing unproductive use of water and agro inputs [103]. They assist farmers in accessing and processing the available data into practical crop water need to know when and how much water to irrigate. DSSs significantly if well coupled with water-saving practices can increase water productivity by over 60%, compared to other irrigation scheduling methods [104]. Much as many attempts have been made to enhance irrigation decisions using DSSs, they have largely remained academic, not been widely adopted and used by the farmers as had been anticipated by the designers [9]. This is partly due to the complexity in the designs [8] and perception of farmers to reduce water use over production, and the effort required relative to the perceived benefit [6]. While a number of irrigation DSSs have been developed globally mainly in fertilizer, pesticides monitoring [4] and horticulture crop support [6] [9], there remains a shortage of rice DSS available to support individual farmers in lowland rice production and water management [101]. DSSs developed for on-farm water management will come in handy to be applied in the FLID arrangement, hence contributing to improving water use efficiency in farmer-led irrigated rice systems enabling farmers to apply the right amount of water at the right time consequently reducing the rice water footprint [105]. In the near future, the farmer's knowledge and access to ICT tools especially for weather forecast will be important for the best farm activities planning, irrigation and production [106]. This will be accelerated by the increasing number of weather forecasting tools through Application Programming Interfaces (APIs) that provide point location weather forecast data in various programmable formats [107]. The FAO Penman-Monteith equation for the estimation of ET using real-time or forecast weather API data can be combined with continuous soil water content monitoring data from soil sensors [32] as applied in the WIDSS architecture. Combining such technologies can help farmers reduce percolation, drainage, and evaporation losses from their fields by about 20% without a significant yield decline [6], [31]. The decision to initiate irrigation shall consider the knowledge of true rice field water availability (soil moisture and ponding water) in the whole area. Utilizing sensor monitoring is a positive step forward for agriculture [74] now and in the future. While DSSs are not readily available to potential users in SSA, access to the same by farmers is grossly lacking. The lack of knowledge of the usefulness of DSS among farmers is worsened by the absence of decision support of critical crops for food security like rice in most DSSs [9], [6] and this hampers the adoption of practices like AWD by farmers. In rice-growing environments, the difference between the potential yield in irrigated lowland or water-limited yield in rain-fed lowland and the actual yield obtained by farmers is largely due to a wide range of constraints including water-related issues [108].

7. Conclusion

Estimation of irrigation requirements and irrigation scheduling (how much water and when, to water) in the low-land rice field at the beginning of every irrigation cycle is a basic problem faced by lowland rice farmers. Most existing DSSs can obtain, simulate, and estimate irrigation schedules and yield response through modeling, but these have largely remained academic, on desktops, and in the hands of technical users. Despite the advancement of technology, there is limited advancement in DSSs that can be installed on mobile phones to generate and relay irrigation schedules and weather forecasts to farmers, and automatically adjust the schedules in real-time as several parameters change in the field. It is important that these DSSs (or the new ones) adopt farmer-friendly, simplified GUIs to allow farmers simplified access to the rather complex simulation models and data. This review further confirms that the visual presentation of decision-making information is one of the best ways to increase the user-friendliness of a DSS. Generally, a simple graphical visualization can hide the complexity of DSSs, enabling farmers to manage agricultural activities more easily and efficiently. The use of on-farm weather forecasting and irrigation schedule forecast DSSs will ease the adoption of AWD water-saving practices by farmers. Key stakeholders like managers, researchers, and governments could assist farmers in their planning if granted access to farmer information. In addition, DSSs keep the users ahead of climate change effects and help in the proper planning of crop production activities and shared water resources, hence saving farmers' time. The farmers will have a chance to contribute directly to improving water use efficiency and saving water that can be used for increased rice production acreage and/or support other sectors. Lastly, research on the cost-benefit of water management technologies, the prerequisites and business models for their widespread adoption, and the effects on farmers' livelihoods, particularly for women and young people in lowlands, has been sparse. However, the management of water resources sustainably and the sustainable intensification of rice-based systems in SSA could both benefit from closing these research gaps.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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