Invited Paper

Ensuring food and nutritional security while facing the looming crisis of drought

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Introduction

Agriculture in Sri Lanka is often challenged by a growing complex of highly connected biotic and abiotic constrains including impacts of climate change. Even though many other growing challenges are threatening the country's humanity, food and nutritional security is the major concern. There was a steady increase in domestic agriculture production until 2021. However, COVID-19 pandemic followed by multi-dimensional economic crisis and ill-advised decision on banning of chemical fertilizers and agro-chemicals resulted Sri Lanka a food unsecured nation. With the removal of 100% organic strategy by the government and the increase availability of necessary fertilizer and agro-chemicals, the agriculture production gradually improved (DoA, 2023). However, with the development of El Niño–Southern Oscillation (ENSO) event in the centra-easter Pacific Ocean by early 2023, there was a reduction in rainfall towards the latter part of 2023 *Yala* season with subsequent reduction of water levels in country's major reservoirs, damaging about 25,000 ha of paddy lands affecting over 50,000 farm families in the Dry and Intermediate zones of the island.

The most ENSO events begin in the northern hemisphere spring (March or sometimes summer (June) and reach its peak from November to January (Trenberth, 1997). Typically, this anomaly occurs at irregular intervals of three to seven years (McPhaden *et al*., 2011) and it is one of the most important climate drivers of the earth due to its ability to change the global atmospheric circulation, which in turn, influences temperature and precipitation regime across the globe. The extremes of this oscillations cause extreme weather conditions, *i.e*., floods, droughts, and heat waves, in many regions of the world including Sri Lanka (Ropelewski and Halpert, 1987).

The IOD or Indian Ocean Dipole is an Sea Surface Temperature (SST) anomaly that occurs in the Western and Eastern Ocean, which can strongly modulate the atmospheric circulations, thereby inducing climate anomalies in many parts of the world, including both Indian Ocean rim countries (Doi *et al*., 2020; Saji and Yamagata, 2003). The interactions between ENSO and IOD are known to have great implications for global climate variability and seasonal climate predictions (Zhao *et al*., 2023). Therefore, influence of ENSO, IOD, their interactions on seasonal climatic regime, especially the predictions on rainfall and ambient temperature, and their impact on overall agriculture and suitable adaptation measures available to overcome such stresses have sparked keen interest in the climate research community across the world and even the general public.

Therefore, this paper aims to ascertain the ENSO and IOD events appeared in the central-eastern Pacific Ocean in the past, its impact on food crop sector and identify possible adaptation measures to minimize the loss and damage to the agriculture sector in Sri Lanka

The Food Crop Sector

With the change in structure of the country's economy over the last decade (CBSL, 2022), the consumer dietary patterns of Sri Lanka have changed significantly resulting in a corresponding change of agri-food systems with increased demand for value added safe foods, which demand a further increase in volume of primary food and feed production in the island. Even though the rate of population growth was 1.1% in 2020, the existing population with a density of 354 persons/km^{-2} (World Bank, 2020) has significantly utilized the arable lands for non-agricultural uses resulting a reduction in per capita land availability for agriculture. Therefore, overall annual land productivity should be increased with efficient utilization of both natural capital and other inputs to ensure sustainable food and nutritional security of the nation.

In 2022, Sri Lanka faced its worst multi-dimensional crisis since independence with persistent fiscal deficits and depletion of foreign-exchange reserves and the impacts of the COVID-19 pandemic. This impact was further exacerbated by the ill-advised based decisions without scientific justification to go for 100% organic, banning import of chemical fertilizer and pesticides triggering a disastrous impact on productivity and production with a significant drop in agriculture production leading to a food and nutrition crisis in Sri Lanka (FAO, 2023).

Agriculture production in Sri Lanka was gradually increasing until the year 2021 (2020/21 *Maha* and 2021 *Yala* season) where production of most food crops increased significantly (Table 1). This increase in production was achieved with increased usage of agriculture inputs and other natural resources, especially irrigation water and fertilizer. Despite increased agricultural production, productivity was stagnating with an increased yield gap between the current productivity and the realizable potential resulting an increased land area requirement to meet the national food demand (Table 1).

Table 1. National requirement, production, and productivity of food crops in 2021 and the land requirement to be self-sufficient at current productivity

Crop	National Requirement, ton	Production in 2021, ton	% production of the requirement	Productivity, ton/ha	Land area cultivated in 2021, ha	Land required to be self-sufficient with current productivity, ha
Paddy	5,000,000	5,149,888	103	4.31	1,259,498	1,160,058
Maize	600,000	472,444	79	4.43	106,757	135,581
Potato	225,000	75,911	34	16.42	4,623	13,703
Big Onion	300,000	65,907	22	16.77	3,929	17,884
Red Onion	75,000	53,783	72	13.28	4,051	5,649
Chili (Dry)	52,000	857	2	1.39	686	37,410
chili (Green)	68,595	68,565	100	5.57	12,301	12,306
Soybean	225,000	4,904	2	2.56	1,915	87,862
Green gram	20,000	18,931	95	1.06	17,842	18,850
Cowpea	15,000	11,879	79	1.14	10,441	13,184
Black gram	20,000	14,404	72	1.05	13,675	18,988
Ground nut	35,000	36,946	106	1.99	18,538	17,562
Finger millet	10,000	8,064	81	1.31	6,138	7,612
Total					200,896	386,590

Source: Department of Agriculture and Department of Census and Statistic, Sri Lanka

Climate change impacts on agriculture

Sri Lanka is considered as a high-risk country to climate change (Global Climate Risk Index, 2020). The variability of northeast monsoon which brings rain to the Dry and Intermediate zones has increased during recent decades with increased occurrence of extreme events. If this trend continues, in future with the climate change, crops cultivated in Dry and Intermediate zones will be exposed to many abiotic stresses such as frequent and intense droughts and floods, thermal injuries due to increasing maximum and minimum air temperatures above the threshold values during the cropping season, and the deteriorating soil environment leading to soil salinity build-up and biotic constraints such as pest and disease outbreaks.

Impending Drought with ENSO

El Niño - Southern Oscillation (ENSO), an irregular periodic variation in winds and SST over the tropical eastern Pacific Ocean influences weather and climate patterns around the world, including the monsoon and inter-monsoon seasons in Sri Lanka. El Niño is accompanied by high air surface pressure in the tropical western Pacific Ocean which occurs on periods ranging from about three to seven years, and sometimes in a row (Bjerknes, 1969). However, there are some instances when the Pacific Ocean can look like it is in an El Niño, but the atmosphere is not playing along, resulting no teleconnections as opposed to observed changes in the history when ENSO events prevailed.

World Meteorological Organization (WMO) report released in May 2023 predicted a 98% likelihood that at least one of next five years, and the five-year period, will be warmest on record, beating the record set in 2016 when there was an exceptionally strong El Niño. The onset of El Niño will greatly increase the likelihood of breaking temperature records and triggering more extreme heat in many parts of the world and in the ocean.

According to the historical El Nino events, it was found that El Nino is impacting temperature and the rainfall pattern in Sri Lanka. Premalal, (2013) identified upper-level positive wind velocity potential and low-level negative wind velocity potential over South Asian region and consequently strong subsidence in the region during El Nino years and it is one of the probable reasons for experiencing higher ambient temperature regime in Sri Lanka during El Nino years. Historical observations have also revealed that high temperature regimes over Sri Lanka during El Nino years. According to the information available at the Department of Meteorology, Sri Lanka, most places of the country have reported high temperatures during the year 2023 contributing strong evapotranspiration. Usually, the Dry zone experiences only less amount of rainfall during the southwest monsoon period and strong evapotranspiration caused by elevated ambient temperature owing to El Nino conditions posed a greater impact on the ground water availability in the Dry zone of Sri Lanka while experiencing faster drying rates in surface water bodies and below average base flows in streams mending across the entire country.

Premalal, 2013 and Hapuarachchi *et al*., 2015 showed the behavior of rainfall pattern in Sri Lanka during the monsoon seasons and in different months with El Nino and La Nina events. The rainfall data from 1974 – 2010 shows a negative anomaly rainfall during the southwest monsoon and positive anomaly rainfall in second inter monsoon during El Nino years (Premalal, 2013).

Indian Ocean Dipole (IOD) also can strongly modulate the atmospheric circulations resulting in climate anomalies in many parts of the world, including both Indian Ocean rim countries and remote areas such as East Asia and South America (Doi *et al*., 2020; Saji and Yamagata, 2003). Although the dynamic source of the IOD lies within the Indian Ocean, the IOD frequently co-occurs with ENSO in the Pacific, which is the strongest mode of tropical climate variability (Wang *et al*., 2016) and the interactions are known to have great implications for global climate variability and seasonal climate predictions (Zhao *et al*, 2023). A few studies carried out on changing rainfall pattern in Sri Lanka with IOD have revealed a positive rainfall anomaly during *Maha* season (Abeyesekera *et al*., 2023; Zubair *et al*., 2003).

Historically, ENSO events have showed negative rainfall anomalies of Southwest Monsoon (SWM) rainfall during May to September. Month of May is the onset of SWM and the negative anomaly of rainfall during June and July will impact for the entire season as mid-July and August are generally dry months. During the Second Inter Monsoon (SIM) season (October and November), there is a clear indication of above normal rainfall during El Nino years. Generally, El Nino events tends to reduce NEM rainfall with a profound decrease of rainfall over north-western, north central, and central parts of the island (Hapuarachchi *et al*., 2015). Studies conducted with the historical monthly and seasonal rainfall distribution during ENSO years have shown very clearly that no favorable rainfall will be experienced during *Yala* seasons. Monthly analysis of observed rainfall of Sri Lanka in 2023 (Department of Meteorology, 2023) suggested a drier First Inter Monsoon (FIM) season over most parts of the island, especially north, north-central, north-western provinces while the SWM is predicted to be very wet during the onset month (May) over most parts followed by a dry June and July (Figure 1a, 1b). The very wet conditions during May in El Nino years could be attributed to pre-monsoon disturbances associated with El Nino circulation, which requires extensive studies to consolidate the existing apparent trend.

The current weather

In 2023, during the SWM, El Niño conditions were evident in the tropical Pacific Ocean. During the month of May, there was an increased rainfall allowing farmers to start cultivation. The SWM established across Sri Lanka on June 8th, 2023, arriving approximately two weeks after the typical onset date of May 25th. The month of June 2023 experienced weak SWM activity with most major meteorological stations reporting below-average rainfall, except

Bandarawela, Mannar, Pottuvil, Vavuniya, Trincomalee, Galle, and Ratnapura. In July 2023, reduced rainfall persisted in most areas of the country, excluding Bandarawela, Jaffna, and Nuwara Eliya. Notably, Anuradhapura, Vavuniya, and Polonnaruwa received hardly any rainfall during the month of July 2023. By August, most stations continued to report diminished rainfall, with the exceptions of Badulla and Batticaloa.

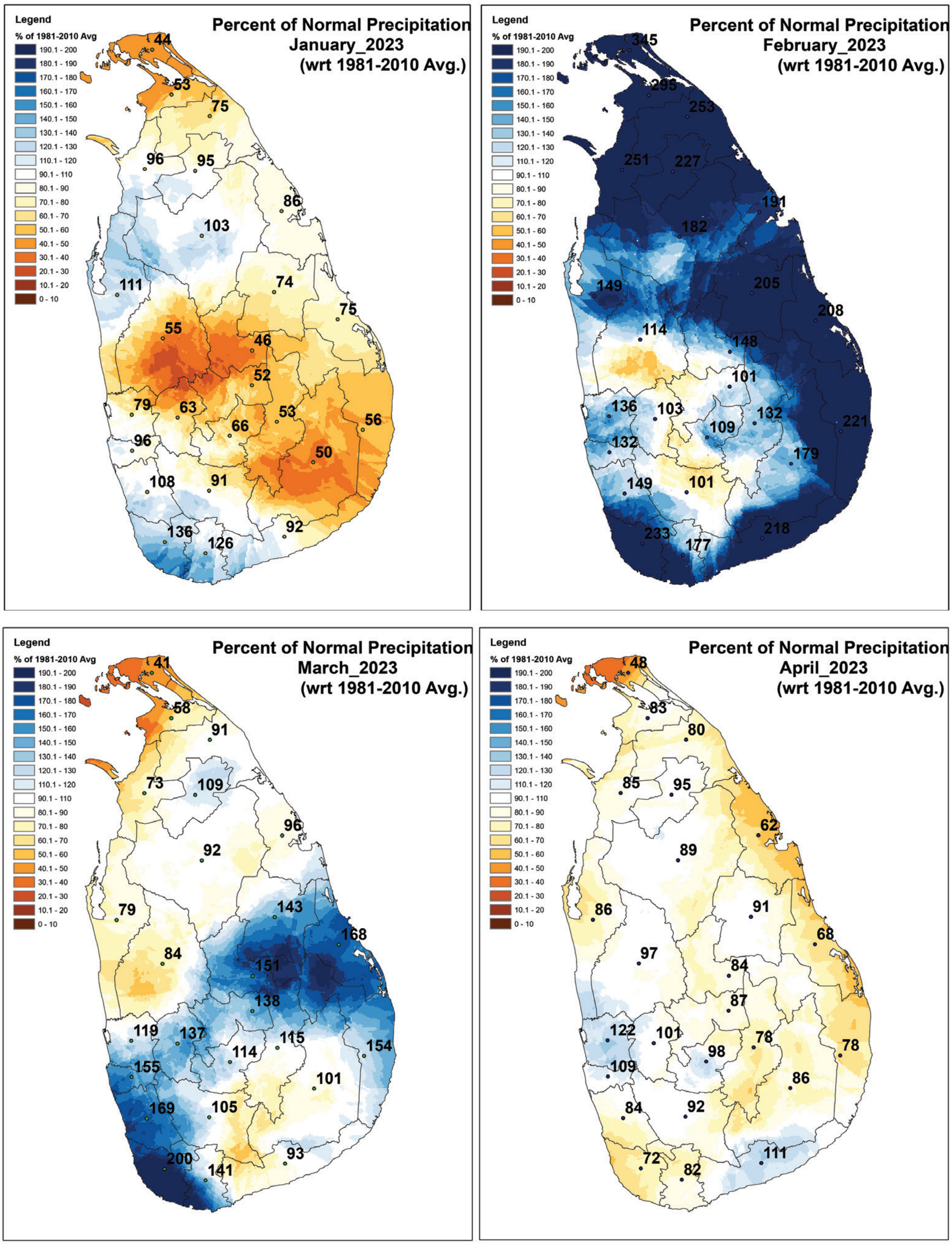

Figure 1a. Rainfall anomaly from January to April, 2023 (Source: Department of Meteorology)

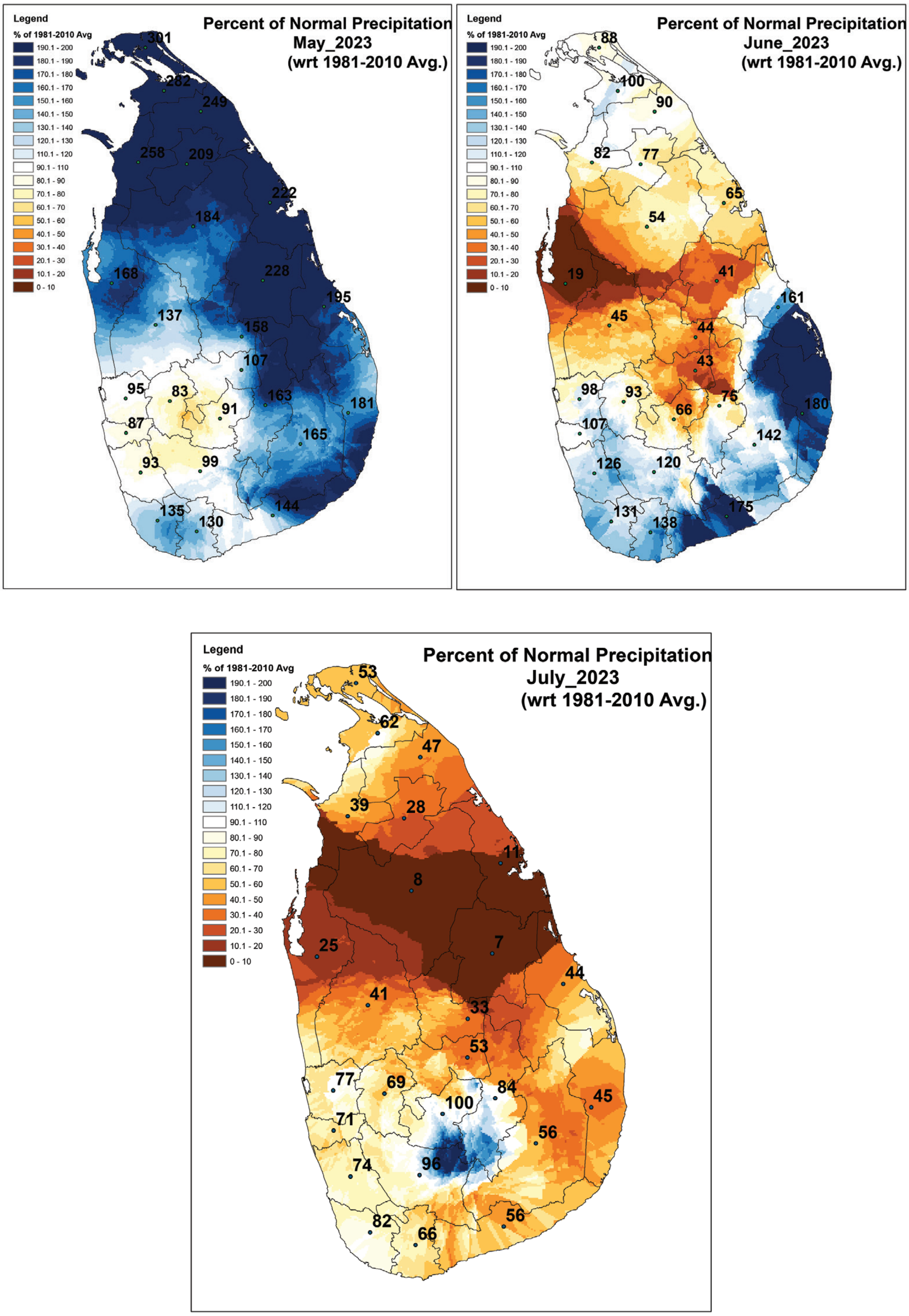

Figure 1b. Rainfall anomaly from May to July, 2023 (Source: Department of Meteorology)

Change of temperature during ENSO

According to global observations and the data available at the Department of Meteorology, temperatures are above normal during El Nino. It has been further confirmed by Premalal (2013) using the analysis of Velocity Potential (CHI) which is large scale ascending (Convergence, Positive CHI) and descending (Divergence, Negative CHI). As predicted, from May 15th to the end of August 2023, most meteorological stations noted temperatures exceeding the climatological averages, especially in August 2023, Anuradhapura and Vavuniya recorded maximum temperatures that were 2 to 5°C degrees higher than the long-term average exacerbating water scarcity due to increased evapotranspiration rates (Figure 2).

Drought impacts on agriculture in Sri Lanka

In the recent past, water scarcity has become a major limiting factor for increased productivity and production of all food crops. The paddy production has fluctuated significantly (Figure 3) since 2012 with a change in weather pattern in spite of 75% of paddy lands cultivated in Sri Lanka are irrigated.

Due to the erratic rainfall pattern and unexpected dry spells, drought has become major abiotic stress factor causing significant yield reductions in paddy cultivation of Sri Lanka during last decade. The reduction in production was mainly due to the reduction in harvested extent. Compared to a normal year, Paddy production declined with drought in 2017 to 2.4 million tons which is a reduction of around 46.1 (49.2% in 2016/17 *Maha* season and 40.1% in 2017 *Yala* season) compared to paddy production in 2016 (CBSL, 2017) recording the lowest paddy production over the last decade, highlighting impact of severe drought conditions to agriculture in Sri Lanka. In most years, there was a considerable gap between the gross sown extent and the net harvested extent in *Yala* compared to *Maha* due to droughts. Similarly, the cultivated extents of all other field crops also declined with the erratic rainfall distribution within seasons.

With this erratic rainfall and extraction of water from rivers for non-agriculture activities, the water flow in the Mahaweli river which feeds the Dry Zone shows a significant reduction of its flow until 2005 and thereafter a greater fluctuation over the years resulting an overall decline in water released towards the downstream (Figure 4). Using approximately 914 ± 117 million m^3 of water diverted annually towards the Dry zone from Polgolla (Figure 4), about 89,775 ha of paddy lands and a sizable upland fraction using lift irrigation are being cultivated in both *Yala* and *Maha* seasons. Assuming diverted water is used only for paddy farming in both *Maha* and *Yala* seasons, a simple calculation suggests a usage of approximately 5,100 m^3 of irrigation water per ha per season. These estimates suggest that when compared to the irrigation water required for a successful 3 ½ month paddy crop in the Intermediate zone (Table 2), during *Maha* and *Yala* seasons, about 50% and 25% of water are overused, respectively, suggesting the need for an immediate intervention in improving the water productivity.

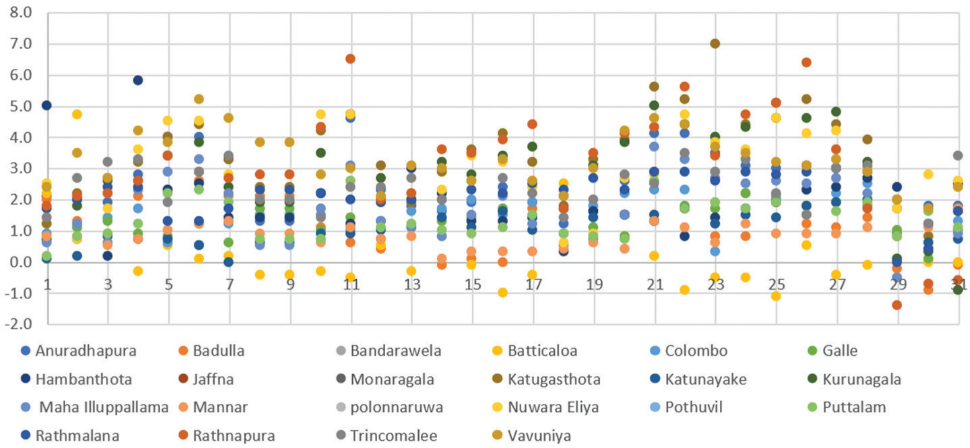

Figure 2. Maximum Temperature anomaly (^{o}C) for August 2023

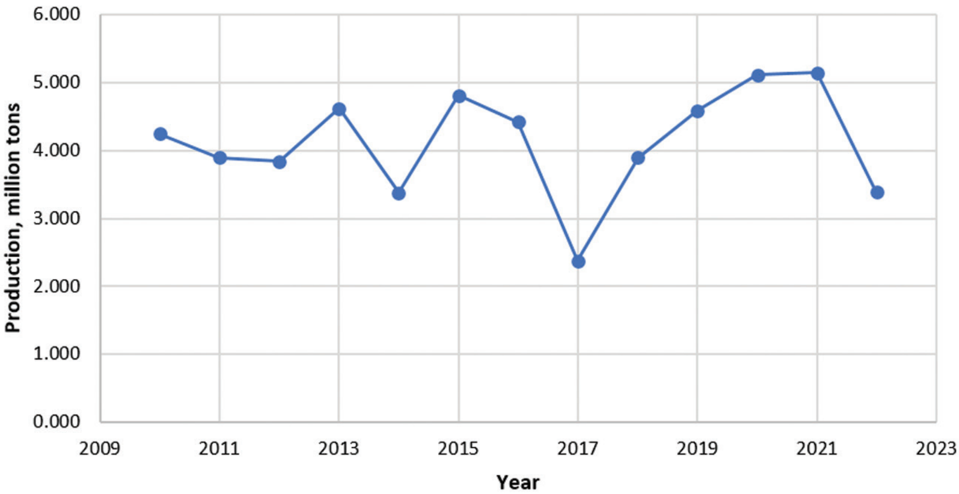

Figure 3. Annual paddy production in Sri Lanka since 2010

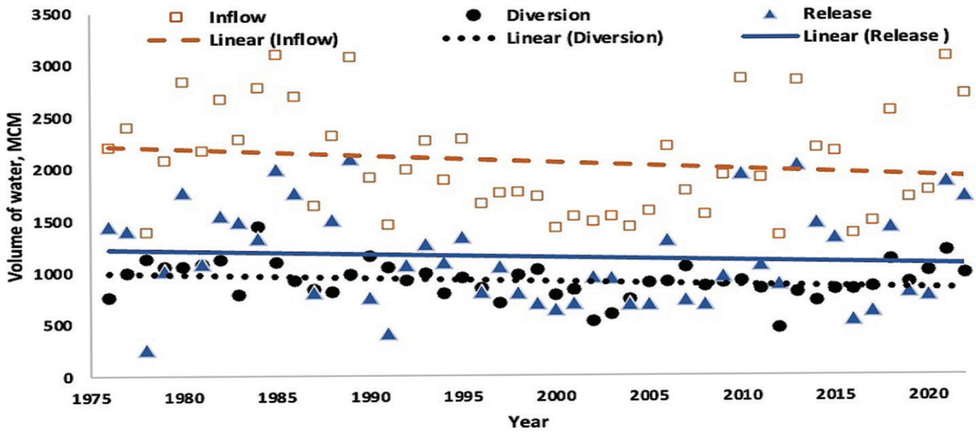

Figure 4. Total flow of water, amount diverted and released down stream of Mahaweli river from Polgolla barrage from 1975 to 2022 (courtesy of Mahaweli Authority of Sri Lanka)

Table 2. Number of irrigation issues and irrigation water volume (m^3) needed to maintain different soil moisture regimes until late booting stage and resulting paddy grain yield ($t\ ha^{-1}$) and water productivity (kg of grain/ m^3 of water used) during 2003 *Yala* and 2003/2004 *Maha* seasons at RRDI, Batalagoda

Treatment	No. of irrigation issues		Amount of water applied, m^3/ha		Yield, $t\ ha^{-1}$		Water Productivity		Leaf greenness, (SPAD value)
	Yala	*Maha*	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*	*Maha*	*Maha*
Standing water up to 2.5 cm throughout	10	5	4426^{b}	2047^{a}	4.74^{a}	5.77^{a}	1.007^{ab}	2.829^{b}	41.6
Irrigate up to 10 cm and allow to recede to saturated level	11	4	5427^{a}	1610^{a}	4.9^{a}	5.75^{a}	0.933^{b}	3.577^{b}	39.1
Irrigate to saturate level when soil start forming cracks	5	3	2872^{c}	523^{b}	4.19^{b}	5.08^{b}	1.45^{a}	9.71^{a}	40.4
Maintain saturate level throughout	9	3	3363^{c}	558^{b}	4.54^{a}	5.46^{b}	1.35^{a}	9.78^{a}	42.5

Improving water productivity

In all irrigation systems, conveying losses are significantly high. A study done in the Mahaweli river basin at Huruluwewa, Maduru Oya and Minipe suggest a significant conveying losses of irrigation water ranging from 50% to 70% in unlined canals and around 40% in lined canals (*Ministry of irrigation*, 2022). Even though, these losses indirectly support agriculture and other uses including recharging of ground water, in an environment where irrigation water availability is reducing (Figure 4), a judicious use of irrigation water is essential to support other needs including electricity generation, thus a novel system of water delivery is essential to maximize overall water duty.

The water productivity of paddy calculated in the field (FAO, 2022) ranged from 0.2 to 1.2 kg m^{-3} with a water consumption of between 3,000 to 5,000 L kg^{-1} of rice. Maintaining Alternate wetting and drying (Rathnayake, 2019) or saturated soil conditions (Weerakoon *et al*., 2010) could save a significant quantity of irrigation water. Experiments conducted at the RRDI, Batalagoda suggest that over 70% of the irrigation water could be saved if alternate wetting and drying or saturated soil moisture condition are maintained in paddy fields throughout the cropping period coupled with correct time of planting while the water productivity could be increased by over 300% (Table 2).

Maintaining rice plants at saturated condition throughout the growing period significantly increased total biomass, root dry weight and leaf greenness than the totally flooded or alternat wetting and drying system of rice cultivation (Weerakoon *et al*., 2010). Soil saturated conditions of paddy soils would prevent soil being exposed to alternate oxidized and reduced conditions, preventing nitrogen losses leading to an increased leaf greenness with N uptake by the plant (Table 2). Maintaining alternate wetting and drying reduced the number of irrigation issues as well as the amount of water applied, but the increased water productivity was more evident where the saturated conditions were maintained throughout the growing season. Therefore, by maintaining either condition, the primary objective of saving irrigation water can be achieved while increasing the productivity, thus water saved could be used for other purposes. A track based systematic methodology to issue water based on the Crop Water Requirement (CWR) and predicted rainfall and strict adherence to water saving irrigation systems in all irrigation schemes is therefore needed.

It is expected that extreme weather events will be more frequent in a future climate, thus improving water storage capacity at every level would be an investment for the future while improving the storage capacity of tanks and rainwater harvesting at household level should also be encouraged.

Maximizing land productivity and natural resource use efficiency

With the impending water limited situation, it is imperative to limit the irrigation water usage while maximizing the usage of rainwater. This could be done by prioritizing crops to be grown by matching with the year-round water availability. Paddy should be grown in seasons and locations where percolation and seepage losses are minimum. During the *Maha* season, it is expected that in all lowlands, only crops tolerant to water stagnation could be grown, thus total lowland area will be under paddy cultivation. However, during the dry season, cultivation of paddy in well-drained paddy field should be discouraged with an alternate crop diversification strategy using other upland cash crops where water productivity and overall return to the investment is relatively high (Table 3).

In rainfed favorable ecosystems, use of drought tolerant varieties during the dry *Yala* season will reduce the risk of drought while boosting the land productivity. Further, irrigation water should not be used for the cultivation of paddy in drought prone ecosystems with a greater risk of water stress and in well- drained irrigated paddy tracks in the Dry and Intermediate zones during *Yala* season. In such environments, cultivation of annual field crops with appropriate crop combinations using advanced production techniques and energy efficient irrigation systems should be practiced (Table 3).

Table 3. Increase in annual net return (Rs per 3.2 ha) to the farmer with diversification of a 3.2 ha paddy field using selected crop combination and appropriate precision farming technologies

	Crop combination (extent in ha)			Net return from 3.2 ha , Rs $year^{-1}$	Net return Rs ha^{-1} $year^{-1}$
	***Maha* (3.2 ha)**	**Mid-season (3.2 ha)**	***Yala***		
1	Paddy		Paddy (3.2)	1,982,679	619,587
2	Paddy	Green gram	Paddy (3.2)	9,049,135	2,827,855
3	Paddy	Green gram	Maize (1.6)	7,240,974	2,262,804
4	Paddy	Green gram	soybean (1.6)	6,939,795	2,168,686
5	Paddy	Green gram	Ground nut (1.6)	9,533,491	2,979,216
6	Paddy	Green gram	Black gram (1.2), Chilli (0.4)	20,363,412	6,363,566
7	Paddy	Green gram	Onion (0.2), Black gram (1.4)	11,220,674	3,506,461

Note – report of a desk study conducted by the Department of Agriculture (A.T. Sooriyaarachchi and R.A.C.J. Perera). Eight crops have been used in different combinations over a year for the computation. In the Yala season, the cost of production included a share of precision farming where a solar pump, agro well and sprinkler/drip irrigation system for 1.6ha plot.

Assumptions: Farm gate price (Rs/kg) – Paddy (100), Green Gram (450), Black gram (500), Maize (150), Green, chilli (250), Onion (150), Ground nut (400); Cost of irrigation kit (Sprinkler) for 1.6ha Rs 2,000,000, Solar pump Rs 2,500,000, Agro-well Rs 500,000, Drip system for 0.2 ha Rs 500,000 with 6 years Life expectancy of the total system based on 2022 market price.

Maximize the utilization of rainwater with collectively and timely (seasonal) cultivation

Timely cultivation with the onset of seasonal rains will maximize the use of rainwater and other natural resources while improving the efficiency of other inputs. A study done by Punyawardena (2002), using 1,000 years simulated rainfall data generated by stochastic modelling suggest that the onset of rains during the *Maha* season at Mahailluppallama in DL_1 agro ecological zone was around mid-October (standard week number 42) which remain active for around 14 weeks while the onset of rain during the *Yala* season is late March (standard week number 13) which last in just 5.3 weeks. This suggests that a sizable quantity of paddy land, even with irrigation water should be diverted to less water requiring upland crops during *Yala* season. Further delayed planting increases the irrigation water requirement and the number of irrigation water issues at later stages. Delaying and staggered crop establishment would increase the susceptibility to biotic stresses. It also affects the growth and the age of the rice crop, especially during the Maha season.

A survey done by Weerakoon *et al*. (2006) revealed that in the irrigated ecosystem, only 12 and 15% of farmers start cultivating paddy with the incipient rains in *Yala* and *Maha* seasons, respectively while 100% of farmers in the rainfed system follow the rainfall pattern in establishing their crop. Therefore. It shall be a mandatory practice in the irrigated ecosystems to start field operations with the onset of seasonal rains and follow a uniform cultivation calendar without any overlapping of different growth stages in each tract. This would help to increase the productivity and reduce irrigation water need while integrating crop management practices on a tract basis would reduce time and resources spent on maintaining individual crops. Therefore, appropriate measures should be adapted to encourage farmers on economizing the use of irrigation water with correct timing of field operations.

Wet Zone is considered as the most trustworthy buffer region for paddy production when Dry Zone fails due to erratic rainfall receipt. With anticipated droughts, every effort should therefore be made to maximize paddy production from the favorable paddy ecosystems in the Wet zone. In general, due to socio-economic issues, unfavorable edaphic environment including poor drainage, the productivity in these ecosystems is low, thus most of the paddy lands are abandoned. However, a sizeable land extent in the Wet Zone ecosystems exists with adequate water and favorable soil and other environmental conditions in parts of WL1a, WL1b, WL2b and WL3 ecosystems. The WL2a ecosystem along the coastal region from Moratuwa to Matara constitutes the so-called “ill-drained” lands of the low country Wet zone and the main problem paddy soils of the country are also located in these lowlands, and thus, there is only a very limited potential in this ecosystem to augment the national paddy production when the Dry zone fails. Those potential paddy lands in the low country Wet Zone should be cultivated with improved production and protection technologies. The issue of labor availability and part time farming in the Wet Zone could be solved through clustering and cultivating of favorable paddy lands of a track using improved technologies and techniques by encouraging village youth entrepreneurial farmers with proper legal agreements while a fair share of return is distributed among ownerships. Drainage improvement should be done by the government to facilitate such intervention.

Use of appropriate cultivar to increase water productivity.

Water requirement for a successful rice crop depends on the variety, specifically the age and the other edaphic and environmental conditions. Even though the potential grain yield of rice could increase with age until about 4 months, irrigation water availability limits the age of the variety cultivated. Therefore, cultivating the total paddy land extent with medium duration (3½ month), high yielding, location specific cultivars with all possible scientifically proven technologies in the *Maha* season would produce 70% of the total rice requirement of the country. Considering the shorter season in the Dry Zone and the multiple usages of water to be irrigated, a limited land extent should be cultivated with high yielding short duration (maximum 95 days) paddy crop allowing production of balance 30% of the requirement.

Rice lines developed for cultivation under aerobic soil conditions which mature around 100 days, tested under both aerobic and normal (standing water) conditions until late booting stage have revealed that an average of 13.2% and 10.6% reduction in grain yield in both 2010 *Yala* and 2010/2011 *Maha* seasons, respectively. Among them, the line with the least reduction in yield, 2.5% and 3.3% in *Yala* and *Maha* seasons with a realizable potential of over 5.5 t ha^{-1}, was released as Bg 377 (Piyasiri *et al*., 2023), which could be an ideal candidate variety for such highly uncertain rainfed environments. Further, Bg 314 which has a deep root system and matures in 95-100 days with a yield potential of over 5.0 t ha^{-1} was recommended for cultivation in drought prone rainfed areas (Piyasiri *et al*.,2021). Therefore, to overcome the impending water limited situations in paddy farming, while using the available varieties, continuous efforts in developing varieties of short and medium duration age class with tolerance to intermittent water stress is a timely need.

Availability of quality seed of appropriate varieties with a maturity duration of 105 days or below is a prerequisite to reduce water stress risk, to maximize yield and to maintain quality of the harvest. However, supply of seed, especially seed paddy in required quantities at an affordable price at the correct time is a challenging task. Therefore, the seed availability for the next season should be ensured through a planned production programme in the previous season and developing better long-term storage systems. Further, self-seed production should be encouraged with the supply of mini kits of seed of identified cultivars with a strong participation of the private sector in the seed industry.

Crop and soil management

Improvement of the soil's physical, chemical and biological status for its sustainability is the key feature to increase productivity while increasing the plant vigor to withstand drought stress. Paddy land preparation in the irrigated Dry Zone of Sri Lanka requires about 16% and 24% of the total amount of water applied, which is approximately 163 mm and 204 mm for the in Low Humic Gley (LHG) and Reddish Brown Earth (RBE) soils respectively (Nayakakorala, 1983). This usage of irrigation water has to be minimized with the use of rainwater for land preparation. Further land preparation activities should be completed in less than 3 weeks to minimize the water use. Dry Land preparation, the "Kekulan" system in both seasons especially during the *Yala* season where possible and the existing "Manawari System" in the Northern and Eastern provinces with light soils should be further encouraged with novel techniques and farm implements.

Establishing the paddy crop without draining the water from the field by practicing seedling broadcasting, popularly known as "parachute method" would not only save water but also reduce transplanting shock, increase weed competitiveness, nutrient absorption capacity and ultimate yield.

Irrigation scheduling should be modulated with the prevailing weather conditions in the area. Use of climate information services for irrigation scheduling can make a significant impact in saving irrigation water. In this regard, updating the maps of rainfall availability, particularly in the rainfed ecosystems and matching varieties for such environments should be available to farmers.

Further, on-farm water distribution should be precise to ensure increased resource use efficiency while increasing productivity. Therefore, plot consolidation where possible with proper land levelling having a minimum gradient towards drainage outlet coupled with plastering of bunds to minimize seepage losses would reduce a significant water loss. Further reducing water losses with puddling is a necessity not only to minimize water percolation, but also to reduce nutrient loss.

Proper ploughing to a depth of about 25-30 cm and enriching soil with organic amendments would facilitate deep rooting and increasing water holding capacity (Wickramasinghe *et al*., 1999). However, if subsurface salinity is present, deep ploughing during *Yala* season would bring saline soil to the top depriving plant growth, thus such practice should be avoided. Therefore, during *Maha* season, proper ploughing, puddling and precise levelling would save sizeable quantity of irrigation water needed for paddy farming and improve the rhizosphere for better root growth, which would also increase the tolerance to intermittent drought and overall productivity.

Use of hydrogels which can absorb water and release when necessary, could be used as soil amendment to increase water availability. However, a detailed investigation of the product, especially, the biodegradability without any long- term harmful impact to the soil should be conducted before a general recommendation to be made.

Sub-surface salinity is becoming a serious problem during the dry *Yala* season especially in the Dry zone irrigated lowlands. Investigations on mid-season yellowing particularly in Polonnaruwa district during *Yala* 2004 revealed that it was mainly due to decrease in nutrient uptake with the buildup of excess minerals in the root zone (Weerakoon *et al*., 2010). With the shifting of cropping season, plant water requirement increased due to increased evaporative demand with heavy dry winds during latter part of *Yala* season which coincided with the peak rate of growth of the rice crop. This peak nutrient absorption period which is about 6-8 weeks after sowing for a 3-3½ month rice crop, coincided with the period of increased salt concentration in the root zone due to upward movement of salt from deeper layers along with capillary rise of water. Such fields should be diversified with other crops or cultivate with salt tolerant paddy varieties.

Once established, water should not be used as an aid of managing weeds. Proper ploughing would also help in minimizing the impact of weeds in rice paddies. Further an exact quantity of water required for crop growth could be supplied based on the predicted weather either by maintaining saturated soil conditions or with alternate wetting and drying until late booting stage. Water is most needed at late booting, flowering and grain filling stages. Therefore, availability of a saturated soil must be ensured during these critical growth stages to minimize unfilled grains in the harvest.

Farmers tend to store water in their field due to the uncertainty of the availability of water with irrigation scheduling. Therefore, trust of the farmers must be developed with a reasonable assurance of the supply of water to the paddy fields by irrigation authorities in respective regions.

Drier and warmer environments are conducive for increased pest and disease infestation and outbreaks. A more concentrated effort integrating management options coupled with early warning systems and technology transferring to farmers on the same should be improved at tract level. Adequate quantities of fertilizer applied, based on crop demand using all Integrated Plant Nutrient Management (IPNM) practices should be practiced. In general, Climate Smart Precision Good Agriculture Practices (CSPGAP) should be promoted to increase production while improving the resource use efficiency.

As the production fluctuation between seasons are expected, maintaining essential food grain reserves as a buffer using medium term storage facilities by the government or public-private partnership is needed.

To achieve all above, a strong farmer commitment is much needed. Organized farmer groups with minimum socio-economic and institutional constraints and with a well-defined role by an agricultural extension worker in organizing farmers for collective and timely cultivation, timely supply of agricultural inputs, facilitating credit and marketing etc. is needed to achieve continuous production of adequate quantities of paddy from rice farming systems in Sri Lanka. Further a suitable risk management option with farmer participation allowing progressive decision making is a prerequisite to safeguard farm operations from impending droughts and other climate induced shocks.

All these interventions should be backed by a sound research and development program. Novel varieties tolerant to both abiotic and biotic stresses, appropriate production and protection technologies with increased water use efficiencies coupled with technologies for crop diversification is required. There is a need for a reliable climate information service enabling informed decision making by farmers and a robust mechanism to assess the impact of possible drought and identify vulnerable farmer communities and design mitigation actions including proactive drought management options.

A firm commitment by all relevant authorities coupled with a strong collaboration with all national and international partners, organizations and private sector is needed to ensure the availability of novel varieties and technologies and field execution of the same to face impending drought situation in Sri Lanka.

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