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PERSPECTIVE ARTICLE

# Weed management role in meeting the global food and nutrition security challenge

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**ABSTRACT**

The global agricultural production must increase by around 70% to meet the food and nutrition demands of 9.9 billion people, by 2050. It was predicted that 670 million people will still be undernourished in 2030. Hence, feasible and cost-effective strategies in the global agri-food system need to be implemented for meeting nutrition security. Weed management played a key role in achieving global food and nutrition security, till to date. In this paper the role of weed management in meeting food and nutrition security is revisited in view of the changed scenario of prevailing unintended ecological imbalance, climate change, water overuse and waste, soil degradation, loss of natural resource quality, and declines in biodiversity, increased herbicide use, and chemical runoff that are decreasing crop growth yields and raising reasonable concerns about the sustainability of the current agricultural methods in meeting the future food and nutrition security. The future role of weed management is discussed in terms of: reducing the continued losses caused by weeds and improving crops productivity and production by reducing yield gap; improving resources (land, water, light, nutrients); improving farmers income; advancement of farmers livelihood; combating climate change and balancing biodiversity. The possible role of climate resilient integrated weed management in playing the intended roles in agri-food system is discussed. In order to play much more sustainable role, the weed management, as an integral part of agricultural production, needs to move away from its mono-disciplinary perspective at targeting weeds to multidisciplinary and multifaceted technological solution to serve as a component of overall technological solutions to improve agricultural production for achieving ever increasing food and nutritional security challenges.

**Keywords:** Climate resilience, Crop yield gap, Food security, Integrated weed management, Nutrition security, Resource use efficiency, Weeds competition

## INTRODUCTION

### Food and nutrition security challenge

The global food and nutrition security challenge is to meet the growing demand for food to an estimated as 9.9 billion people by 2050, an increase of more than 25% from 2020. The global agricultural production must increase by around 70% by 2050, to satisfy a growing demand for food. Food insecurity can disrupt agricultural efforts and economic growth and hence future efforts should aim at reducing poverty while providing access to nutritious foods as per growing population's food and nutrition demand.

The term nutritional security refers to the intake, in an adequate amount, of food enriched with essential nutrients. The calories that are available to a higher percentage of the world's population are greater today, than earlier. Yet, 828 million in 2021 are undernourished (food insecurity) (FAO, IFAD, UNICEF, WFP and WHO 2021) resulting in wasting and stunting with 2 billion lack essential nutrients (Haddad *et al.* 2014; Huang *et al.* 2020) causing a reduced potential to attain full physical and cognitive development, while 2 billion suffer from over-nutrition resulting in excess weight or obesity (Haddad *et al.* 2014; Huang *et al.* 2020). In the United States, 42.2 million citizens are suffering from inadequate access to nutritious food–suffering from either hunger or obesity (https://www.aplu.org). The food insecurity varied in different regions of the world (**Figure 1**). It was predicted that 670 million people will still be undernourished in 2030. The global threat to food and nutritional security, due to the growing population, addresses the need to implement feasible and cost-effective strategies in the global agri-food system.

Climate change, including weather extremes and variability of temperatures and rainfall patterns, is already affecting agri-food systems and natural resources and is expected to threaten farm productivity, decreasing harvests and accelerate

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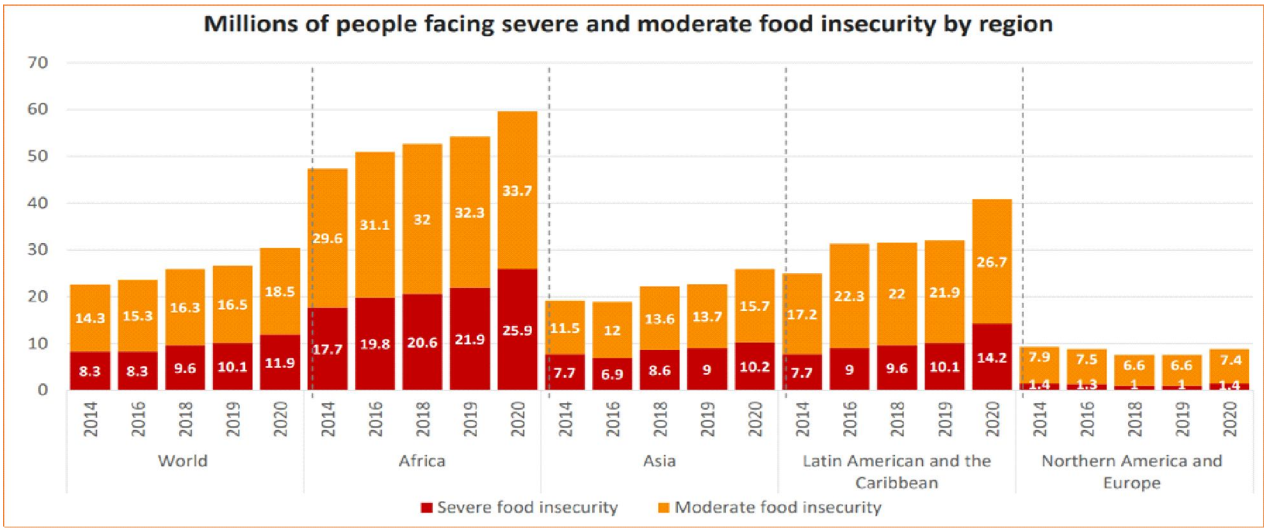


**Figure 1. Food security differences in the world and its different regions** (Source: FAO, IFAD, UNICEF, WFP and WHO. 2021)

hunger and poverty (FAO 2022). The direct effect of climate change on food systems is on the crop production. A study on the climate change impact on the yields of the top ten global crops–barley, cassava, maize, oil palm, rapeseed, rice, sorghum, soybean, sugarcane and wheat indicated that the percentage change in recent yield over all harvested croplands ranged from -13.4% (oil palm) to +3.5% (soybean) (Ray *et al.* 2019). Among the top three global cereals, recent yields have decreased for rice (-0.3% or ~-1.6 million tons (MT) annually) and wheat (-0.9% or ~-5.0 MT annually) and increased negligibly for maize (0% or ~0.2 MT annually) which means an annual 0.4%, 0.5% and 0.7% decrease in consumable food calories available globally from rice, wheat and maize, respectively. The range of impacts of mean climate change on crop yields and production in different regions was observed indicating the underlying variations and interactions of the agro-meteorological conditions and crop management, whose understanding is vital to achieve food and nutrition security in a sustainable manner. Climate change also reduces levels of nutrients in plant-based foods (particularly cereals and legumes) as a result of increased levels of carbon dioxide in the atmosphere (Myers *et al.* 2014).

The possible way to achieve food and nutrition security, in the era of climate change, is to identify the biological and physical constraints and sustainably alleviate them by developing and implementing location specific technologies that improve total factor productivity of agri-food systems.

**Weeds and agri-food systems**

One of the main causes of the chronic food insecurity witnessed in the world is poor crop yields, largely caused by pests including weeds which are causing the loss of more than 40% of the world's food supply (Carvajal-Yepes *et al.* 2019) with the highest losses in food-deficit regions with fast-growing populations (Savary *et al.* 2019). Amongst the pests, weeds cause the highest potential crop yield loss (34%), while the insect pests and pathogens cause 18 and 16% losses, respectively (Oerke 2006).

Weeds have the ability to survive under adverse condition, as they extract more water, nutrients and other resources thereby reduce crop yield by 10 to 80% (Rao and Chauhan 2015; Singh *et al.* 2018). The crop yield losses due to weeds depend on several factors such as associated weed flora, weed emergence time, weed density, type of weeds, crops, cropping systems and management practices used (Rao *et al.* 2007; Rao *et al.* 2014). In monetary terms, the reported annual losses due to weeds varied across different countries [*eg.* AU$ 3.3 billion in Australia (Llewellyn *et al.* 2016); US $ 11 billion for ten crops in India (Gharde *et al.* 2018); the potential spring wheat production loss due to weeds was estimated as 4.8, 1.6, and 6.6 billion kg with a potential loss in value of US$1.14, US$0.37, and US$1.39 billion for the United States, Canada, and combined, respectively (Flessner *et al.* 2021); potential loss in value for corn is $27 billion and for soybean is $16 billion in USA based on data from 2007 to 2013 (https://wssa.net/wssa/weed/croploss-2/)]. Certain weeds like red rice (Morat *et al.* 2018) and *Parthenium* (Sushilkumar 2014, Corin *et al.* 2017) alone cause tremendous crop yield losses and can have significant impacts on global food security. An empirical case study on the economic, environmental, and food security impact of red rice infestation in the U.S. indicated that losses under a moderate infestation scenario from 2002 to 2014 amount to 5.7 million tons or 6%, which is enough to feed 12 million additional people a year, with an environmental cost of $457 million (Morat *et al.* 2018).

In addition to causing enormous crop yield losses, weeds reduce resources (land, water, nutrients, light, energy, labor) use efficiency and crop quality, serve as alternate hosts to several pests and diseases, cause health (skin and respiratory) problems to human beings, waste human energy and increase cultivation cost to manage them. Weeds infestations can result in livelihood impacts beyond crop yield losses, with school age children spending time weeding instead of attending education classes and limiting future prospects. Many of the weed impacts may be difficult to quantify economically, but are significant if the true costs of weeds are considered. To ensure food security on sustainable basis, reducing weeds interference and boosting resources use efficiency are critical.

The negative impacts of weeds may be prevented, or contained, by implementing weed management measures including cultural (cultivar choice, crop rotation, tillage, mechanical weeding, *etc*.), preventive, biological (parasitoids, predators, *etc*.) and chemical measures (biopesticides and herbicides) (Mishra and Singh 2012; Ramesh *et al.* 2017, Rao *et al.* 2021). The progress made so far on developed weed management methods will not be discussed in this paper, in detail, as the research progress in weed management in different countries and weed management approaches, developed and used so far, were reviewed earlier (Rao *et al.* 2014; 2015, 2020; Rao and Yaduraju 2015; Mishra *et al.* 2016; Rao and Matsumoto 2017; Westwood *et al.* 2018; Dilipkumar *et al.* 2020; Zhu *et al.* 2020). Recently, the climate resilient integrated weed management approach (CRIWM) has been suggested (Rao 2022).

**The need for revisiting the role of weed management**

Global food production increased enormously during the second half of the twentieth century, keeping pace with population growth. Taking 1961 as a base year, average yields of staple cereals have increased throughout the world, but to different degrees. The strongest increases have been witnessed in Latin America where average yields are more than four-fold larger. In Europe and in (irrigated) agriculture in Asia, yields have doubled or tripled but more modest increases of around 70% have been observed in Africa (Giller *et al.* 2021). Different regions of the world have expanded food production along contrasting pathways. The green revolution has relied greatly on intensification and agrochemicals to increase yields (Tilman *et al.* 2002) and caused unintended ecological consequences leading to a slowdown in yield growth, water overuse and waste, soil degradation, natural resource quality loss, and biodiversity decline, pesticide use increase, and chemical runoff are decreasing crop growth yields and raising justified concerns about the sustainability of the current agricultural methods (Tilman *et al.* 2002; Robertson and Swinton 2005). Such environmental degradation will trigger substantial losses in food supply capacity by 2050.

The climate change, together with other global changes in water availability, and land cover, and altered nitrogen availability and cycling (all strongly influenced by human activities), has increased concerns about achieving global food security (Rosegrant *et al.* 2014). The global agri-food systems have become vulnerable to ongoing climate change which has reduced global agricultural total factor productivity (TFP) by about 21% since 1961 with substantially more severe (a reduction of ~26–34% in warmer regions (Ortiz-Bobea *et al.* 2021). The stagnation of crop yield (Grassini *et al.* 2013) and the overall decline in total factor productivity (Ortiz-Bobea *et al.* 2021) necessitates the revisit the agricultural technologies. The unsustainable agri-food systems reduce the access to affordable, healthy diets, increasing their risk of poor health and diet-related diseases (Fanzo and Downs 2021). Thus, the agricultural research should focus on developing agri-food systems and technologies that meet both production and environmental targets together while enabling farmers adapt to other emerging challenges, such as water deficit/abundance, pesticide/herbicide resistance, yield plateaus, and the changing climate (Hunter *et al.* 2017).

Weeds are the universal constituents of global agri-food systems causing varying negative impacts and one of the most vital challenges in agriculture due to their capacity to quickly adapt to weed management practices and the changing climate. Hence, weed management plays a key role in attaining the intended food-nutrition security. Herbicides are commonly used for managing weeds in developed world and herbicide use is increasing in developing world. Herbicides constitute half of the consumed 4 million tons of pesticides worth 84.5 billion USD in 2019 and is expected to be 130.7 billion USD by 2023, globally. The discovery of new herbicides has declined significantly over the past few decades and herbicide-tolerant or herbicide-resistant crop technologies have allowed the use of available nonselective herbicides to manage weeds in crops

(Kraehmer *et al.* 2014). The overreliance on herbicides for weed control by farmers of the world, for a long period of time, has resulted in selection of weeds with resistance to herbicides in many countries (Heap 2022). More herbicide-resistant weeds are expected in future, especially in developing countries as their economies grow and where herbicide resistance is currently under-reported (Hulme 2022). Any effort involving improvement in food grain production to meet current and future food demands and double the farmers' income must involve weed management (Rao *et al.* 2017). The growing demand for agri-food products requires to explore innovative ways of managing weeds for attaining current and future food and nutrient security, under a changing climate and loss of biodiversity. The innovative ways can be identified, experimented, fine-tuned and adopted only when we revisit existing technologies and identify each component technology role in managing weeds under changing scenario of agri-food system.

In this paper, the weeds impact in aggravating the existing food and nutrition challenge is explained, the role of weed management in attaining food and nutrition security is revisited and the components of climate resilient integrated weed management (CRIWM) to combat specific challenges are specified for further strengthening to play key role in technological inputs of agri-food systems for meeting global current and future food and nutrition goals.

## THE ROLE OF WEED MANAGEMENT

Weed management proved to be an important component of agricultural technology that enabled agriculture to produce food as per the needs of increasing population, so far. The current situation of global food and nutrition demands and currently prevailing adverse conditions in agri-food systems necessitates Weed Scientist to revisit the role of weed management to ascertain how the available knowledge be utilized and on which areas research should be focused to evolve technologies needed to successfully meet the challenge of food and nutrition security, in years to come. Different roles of weed management in improving agri-food systems productivity, sustainability and profitability are discussed briefly.

### Reducing the losses caused by weeds and improving crops production by reducing crops productivity gap

Large yield gaps (the gap between actual production and the best crop yield achievable with available crop varieties, technologies and management) exist in irrigated and in rainfed agriculture (Giller *et al.* 2021) in both Africa and Asia indicating that there is still an enormous potential for improving crops productivity. The crop protection could help farmers increase crop productivity and production by the management of diseases, insects and weeds, which could result in 20-30% global increases of maize, rice and wheat yields (Rosegrant *et al.* 2014). Amongst pests, weeds cause more yield losses than others and the yield gaps due to the crop losses caused by weeds must be highest as unmanaged weeds cause loss up to 100%. Weed control accounted for 30% of crop yield losses, while pests and diseases together accounted for 50% of the difference in sugar beet yield between growers (Hanse *et al.* 2018) and the weed management represents one of the critical agronomic strategies to fill the yield gap, improve crop productivity and reduce yield gap (Eash *et al.* 2019, Peramaiyan *et al.* 2022).

IWM technology was proven to successfully bridge the crops yield gap, thus, enhancing crops productivity in different countries of the world (Rao and Nagamani 2010; Alagbo *et al.* 2022; Peramaiyan *et al.* 2022; Rao *et al.* 2017a; Rao 2022 ). The climate change has already affected global food production (Ray *et al.* 2019). The suitability of crops to a particular region and weeds associated with the crops will change as a result of climate change, and as a consequence crops area may shift. Potential crop weed competition and crop yields in particular climate-soil zones will change and hence yield gap may alter. The CRIWM strategies need to be identified and used to fill yield gaps under climate change scenario (Rao 2022).

### Improving resources use efficiency

The sustainable management and utilization of natural resources, including land, water, air, climate and genetic resources for the benefit of present and future generations (FAO 2022). Increasing crop production is thus an important challenge in addressing economic growth, alleviating poverty and arresting environmental degradation across the world. Cereals [including rice, maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench)], pulses and oil seeds are the most important food and cash crops for millions of rural farm families in the predominantly mixed crop-livestock farming systems. The efficient production of cereals and oil seeds, per unit of input, is therefore central to the food security challenge. Weed Science is not just about weed control and it should help show the way in shaping and improving our management of all natural resources (Chandrasena and Rao 2017).

Weeds compete severely with crops that have similar resources requirements for optimal growth and thus management practices designed to improve crop yield may also help the weeds growth and development. One of the approaches to face the challenge is production of crops with increased input resource use efficiency by managing impediments such as weeds, which are adaptable to all adverse environments and compete with the crops for utilization of land, labor, light, nutrients and water resources and reduce crops productivity, leading to low efficiency of input use, suppressed crop output and reduced food security (Yaduraju and Rao 2013) .

**a. Land use efficiency (LUE)**

1,550 Mha of land is being cultivated (Deininger and Byerlee 2011). There is no or very little new land to bring under cultivation in the land-scarce countries and regions such as Eastern Europe and Central Asia, East and South Asia, Middle East, Near East and North Africa, Australia and other countries (Bruinsma 2009; Blomqvist *et al.* 2020). In sub-Saharan Africa and Latin America, with some in East Asia large tracts of land with varying degrees of agricultural potential without adequate infrastructure or to be protected for environmental reasons (Tilman *et al.* 2001), or lack access to appropriate agricultural technologies or the economic incentives to adopt them (Bruinsma 2009). The crop production increased dramatically, so far, without a corresponding expansion of cropland area due to improvement in agricultural practices (Blomqvist *et al.* 2020). Hence, in future too, for the increased crop production without disturbing ecological balance, the crop productivity increase will remain as the driving force behind the majority of crop production gains.

Weeds compete with the crop for the land too by covering crop land space available for crop growth. When weeds shade crop plants, less sunlight is available for crop production ( Gianessi and Sankula 2003). The most obvious way to improve the LUE is adoption of components of CRIWM such as intercropping which was proved to suppress weeds and increase land equivalent ratio (LER) which is the ratio of the area under sole cropping to the area under intercropping needed to give the same yields. The intercropping strategies saved 16–29% of the land as compared to mono-cultures grown under the same management as the intercrop (Li *et al.* 2020). The choice of legume for intercropping with cereals determines the productivity of intercropping systems by ensuring compatibility in utilizing growth resources (Iqbal *et al.* 2019). The green gram (*Vigna radiata* L.) and black gram (*Vigna mungo* L.) may impart sustainability to cereal-legume intercropping system by enhancing LUE attained through higher utilization efficiency of farm applied inputs. Intercropping produces from about 16% to 30% greater yields on a given piece of land than do each crop species cultivated in monoculture and helps in suppression of weeds (Himmelstein *et al.* 2017; Martin-Guay *et al.* 2018).

Utilization of weed smothering ability of component crops coupled with adoption of best weed management in inter cropping systems was reported to increase LUE by 47% (Rao *et al.* 2017). The maize-green gram intercropping hold potential to impart sustainability to maize production by reducing weeds infestation (431% lower than sole maize) and could be a viable option for smallholder farmers in semi-arid environment (Abbas *et al.* 2021). The optimization of intercropping system may potentially reduce the degree of inter and intra species competition and boost the resources use benefits offered by cereal-legume intercropping systems (Amos *et al.* 2012). Other component of CRIWM *viz*. a crop rotation, and more crops per year, maximizes land productivity (Zohry and Ouda 2018).

**b. Water use efficiency (WUE)**

The water is becoming increasingly scarce and expensive across the world due to its excessive exploitation of water, climate change induced rise in temperatures and erratic rainfall patterns and resulting ground water depletion. Management of water resource and improving WUE are the most challenging since the agricultural sector consumes 70 % of this resource that cannot be replenished. The crop yield gap reduction is often limited by "economic water scarcity" due to several economic and ecological reasons in both developed and developing countries (Jägermeyr *et al.* 2016, Rosa *et al.* 2020). Weeds use water which could be used by the crop. Thus, efficient and improved irrigation technological components of CRIWM can be used for managing weeds and improve WUE.

The weed-crop competition for water depends on the relative growth of the crop vs. the weeds and plant stress status depends on the light intercepted and soil water reserves depletion rates (Berger 2007). Weeds competition for moisture under moisture stress conditions cause crop yield loss of more than 50% depending on weed density and the plant's physical characteristics (Abouziena *et al.* 2015). Water transpired by weeds could aggravate crop drought stress in dry periods through increasing soil moisture deficits, resulting in a decrease in crop water use efficiency. The processes in crops/weeds WUE in crop-weed systems are intertwined in arable lands, owing to crop-weed competition and overlapping drivers (Singh *et al.* 2022). To increase the crops water use efficiency, an important measure adopted is the control of weeds as weeds utilize a considerable amount of soil water (Rao and Shetty 1983; Farooq *et al.* 2019). An increase in WUE of 30 to 70% was obtained with weed management in maize (Borza 2018).

In maize-wheat cropping system in India, higher grain yield, enhanced water productivity and profitability were obtained when irrigation was applied, using drip irrigation system, either at 80- or 120-mm cumulative pan evaporation (CPE) coupled with pre-emergence application (PE) of atrazine 750 g/ha or post-emergence application (PoE) of tembotrione 120 g/ha in maize and CRI + 75 or 100 mm CPE in with of clodinafop + carfentrazone 60 + 20 g/ha PoE or pinoxaden + metsulfuron 50+4 g/ha PoE in wheat (Rawal *et al.* 2022).

An eco-friendly weed-control and water-conservation technology for direct-seeded rice saved about 40% in irrigation and costs of cultivation without any yield penalty, when compared to the high cost of labor and inputs for transplanted rice (Yaduraju *et al.* 2021). Technological adoption of micro-irrigation systems in different crops was reported to cause minimized weed problems (Kumar *et al.* 2022; Mohanpuria *et al.* 2022), improves water productivity (Mohanpuria *et al.* 2022), saves more than 60% water and increases the yield by 30-40% over traditional methods (Magar and Nandgude 2005), enhanced inputs use efficiency and also reduced expenditure on weed management (Kumar *et al.* 2022). It is possible to increase in irrigated area by saving water through best weed management and utilize saved water for bringing more area under irrigation (Rao *et al.* 2017). Intercropping is a sustainable way to offers ecological mechanisms for weed suppression, efficient use of water and increase crop productivity (Rao and Shetty 1983a; Li *et al.* 2020).

Soil mulching component of IWM can cut evaporation by around 75%, cuts water loss from 0 to 30cm soil depth, raises soil water storage (up to 41%), increases grain water use efficiency by 14% (Abouziena *et al.* 2015). The weed management with organic or plastic film mulching, and different conservation tillage systems improved crop grain yield remarkably while conserving soil moisture (Liu *et al.* 2014). Maize, wheat, cotton and potato yields have increased by 33.7%, 33.2%, 26.1% and 36.7%, respectively, while their corresponding water use efficiency levels have increased by 38.9%, 30.2%, 30.2% and 37.8%, respectively with plastic mulching in China (Yan *et al.* 2010). Plastic mulching, a technique to cover the soil around the root zone of a plant with a plastic film, is a useful practice to restrict weed growth, conserve moisture and reduce the effect of soil-borne disease. In addition to preventing weed growth, plastic mulch also causes soil disinfestation due to solarization; soil cover for heat absorption; minimization of evaporation and escape of fertilizer; insects repelling or attracting; and soil temperature manipulation (Patle *et al.* 2020).

The opportunities exist to enhance crops WUE through adoption of CRIWM practices such as tillage, time of crop planting, crop establishment method, cover crops, drought tolerant weed competitive crop cultivars, and herbicide use (Rao 2022).

### c. Light use efficiency (LUE)

The cultural weed management practices such as using smother crops and narrow row spacing exploit plant light responses to promote crop growth and suppress weed growth while improving LUE. The LUE can be improved by understanding weed/crop interactions the physiological and morphological responses of crops and weeds to light, particularly in these times of climate change. Light interception pattern and leaf area index (LAI) observations revealed that inclusion of smother crop viz, cowpea and mungbean resulted In quicker and earlier attenuation of maximum LAI and percentage of light by crops (Rao and Shetty 1981). Intercropping is a sustainable way for weed suppression, efficient use of light and crop productivity improvement (Li *et al.* 2020)

### d. Nutrients use efficiency (NUE)

The nutrients are essential for crop growth along with water and, as demand for food grows, so does demand for fertilisers too. The macro- and micro-nutrient deficiency in soil has been assessed across many parts of the world, thus limiting the nutrient uptake in plants and ultimately in humans (Dhaliwal *et al.* 2022). Hence, globally many countries are facing silent epidemics of nutritional deficiencies in human beings and animals. The lack of diversity in diet, i.e., cereal-based crops deficient in mineral nutrients is an additional threat to nutritional quality (Dhaliwal *et al.* 2022). Thus, diversified crops with optimized by balanced nutrient availability and increased nutrient use efficiency of crops by managing crops and weeds is essential.

The NPK content of the weeds was reported to be higher as compared to the crop plants resulting in reduced nutrient use efficiency. Adoption in different crops the improved CRIWM practices such as mulching (Ram *et al.* 2017), use of competitive crops (Rao and Nagamani 2007), inter cropping (Choudhary and Choudhury 2016 ), appropriate crop establishment methods (Rao *et al.* 2017), tillage (Monsefi *et al.* 2014), cover crops (Ullah *et al.* 2020), water management, optimal fertilization schedule adoption (Rao and Ladha 2011), and use of appropriate nutrient source (Ghosh *et al.* 2020), etc. was reported to increase crop nutrient uptake and use efficiency. Across Sub-Saharan Africa, the traditional maize systems maintain productivity while reducing biotic constraints such as weeds by intercropping or rotating leguminous trees and shrubs, and annual legumes with maize (Snapp *et al.* 2010; Ajayi *et al.* 2011), or by incorporating legume weed residues into croplands (Mapfumo *et al.* 2005). The extrapolation of such technologies should be encouraged.

In rice, improved weed management adoption was reported to cause reduced input use, increased energy output and energy use efficiency. Achievement of a mean 54% higher grain energy yield with a 104% increase in economic returns, 35% lower total water input, and a 43% lower global warming potential index was observed (Ladha *et al.* 2015) in a study conducted at different countries in South Asia, when integrated weed management was a component of best management practices, conservation agriculture and crop diversification (Ladha *et al.* 2015). Thus, weed management plays a key role in improving resources use efficiency while improving crop productivity to help increase food production and attain food and nutrition security.

**Improving farmers' economic returns**

FAO estimated there are about 570 million farms in the world, of which about 475 million (about 84 %) are small (≤2 ha) (Lowder *et al.* 2014). About 92% of all farms are located in developing countries. Smallholder farms will continue to produce the major share of the food in rural areas and will be critical to the food security of a large proportion of the world's population (Giller *et al.* 2021). Majority of the research findings on integrated weed management proved that managing weeds, irrespective of method of establishment, by the use of herbicide or their combinations in integration with hand weeding results in increased economic returns of small holder farmers (Rao and Ladha 2013). For example: crop rotations are a component of CRIWM. The increases in crop productivity can also be achieved by improving cropping system yield by adopting crop rotations through modification of spatial and temporal arrangement of individual crops (Zohry and Ouda 2018). Inclusion of weed smothering pulse crops helps in improving nutrition security. In multiple cropping feasible environments, with a longer growing season, capture of resources, crop yield, the farmers income and livelihood are often improved (Gaba *et al.* 2014; Guilpart *et al.* 2017). An eco-friendly weed-control and water-conservation technology for direct-seeded rice uses less energy and fertilizer consumption in DSR with lower production costs than in transplanted rice and higher economic returns (Yaduraju *et al.* 2021). Enhancing smallholders' production capacities and their economic and social resilience may have a positive impact on food security and nutrition at different levels (Riesgo *et al.* 2016).

**Advancement of the farmers' livelihood**

Agri-food systems directly employ over 1 billion people and provide livelihoods to another 3.5 billion (FAO 2022a). Labour inputs into African and Asian smallholder agriculture are very high and a shortage of labour from land preparation through to harvest, but especially for adequate weeding, is a widespread and severe constraint to crop production (Ogwuike *et al.* 2014; Leonardo *et al.* 2015). The scarcity of agricultural workers in developing countries is due to migration of rural labours to multi-cities for industrial work in crop growing season. The migration of labor to cities can be avoided by improving their livelihoods in rural areas. Weeds use is one of the important components of CRIWM. Farmers may be encouraged to utilize the weeds, prior to flowering, to initiate simple processing units to make vermicompost or compost and market to earn additional income (Rajkhowa *et al.* 2005, Chandrasena and Rao 2019). Medicinal and pharmaceutical properties of weeds (Ekwealor *et al.* 2019) also can be a profitable venture for rural areas to improve their livelihoods.

The improved weed management technology is knowledge intensive and needs to be extended to farming community to improve the crops productivity and farmers income (Rao *et al.* 2014a). The livelihood of rural youth/labor can be improved along with farmers using the technology if they are trained on improved weed management technologies of CRIWM and encouraged financially to initiate custom hiring centers to give improved equipment such as drones for herbicide application and improved automated mechanical weeders/implements (Balas *et al.* 2022) used in precision weed management (Monteiroand Santos 2022). In future, many more knowledge intensive weed management technologies based on computing power, artificial intelligence, deepfield robotics, big data or digital farming, automated weed control and precise spot spraying of herbicides will emerge (Westwood *et al.*

2018, Korres *et al.* 2019. Amend *et al.* 2019) and weed management will play much greater role in improving the farmers income and livelihood.

**Combating climate change impact**

Agriculture accounts for about 14-24 per cent of greenhouse gas (GHG) emissions. Addressing the challenges of climate change, and improving food security will require increased food production with reduced emissions of GHG and make agri-food systems more resilient to shocks and climate change negative impacts. The climate change may be mitigated by adoption of CRIWM approach which involves weed management components like improved agronomic practices, direct-seeding, location specific climatic conditions adopted weed competitive crops and cultivars, location specific nutrients/fertilizer/irrigation/ herbicide application and the conservation agriculture components like zero tillage, crop rotation and crop residues mulching (Rao 2022).

The genetically modified herbicide tolerant crop cultivar technology component of integrated weed management decreased the carbon emissions and allowed more carbon to be retained in the soil due to utilization of practices such as reduced tillage with farm equipment, decreased burning of fossil fuel and use of relatively lesser quantity of herbicides with lesser EIQ values (Brookes and Barfoot 2020). However, over reliance on the use of glyphosate by farmers and the lack of crop and herbicide rotation by farmers, in some regions, has contributed to the development of weed resistance (Brookes 2022). The widespread adoption of transgenic crops carrying foreign genes have also concerns of potential toxicity and allergenicity to human beings, potential risks such as chances of gene flow, adverse effects on non-target organisms, evolution of resistance in weeds (Kumar *et al.* 2020). Hence, cautious approach, with strict adoption of stewardship guidelines adoption, is essential .while using the technology for combating climate change, improving crop production which is essential for food security.

**Balancing biodiversity**

The global warming, natural habitats destruction, deforestation and exposure to pesticides have contributed to the loss of biodiversity (FAO 2021, Renard and Tilman 2021) which impact food systems in a variety of ways including loss of crop diversity, traditional varieties, and lower in-field diversity, increases vulnerability to climate change and increases crop failure. The weed management component, intercropping, along with crop biodiversity, helps lead to greater and more stable yields, decrease land clearing, and lower the use of harmful agrochemicals (Renard and Tilman 2021).

Weeds are also a part of the primary producers within farming systems and are an important component of the agroecosystem as weeds play an important role within agroecosystems in supporting biodiversity (Marshall *et al.* 2003). Weed diversity is indicative of the wider sustainability of the whole cropping system (Storkey and Neve 2018) as weed species support a great diversity of wildlife, including insects, which use them as larval food plants (Capinera 2005). The presence of non-crop plants, such as weeds, can also have agronomic benefits, including nutrient cycling and improvement in soil physical properties (Blaix *et al.* 2018). The maintenance of biodiversity by CRIWM would allow weeds to provide resources that attract and maintain populations of parasitoids, predators and pollinators and can make crops less attractive to pests, thus acting as trap crops (Balfour and Ratnieksps 2022). Thus, an appropriate climate resilient weed control measure plays a key role of balancing the weeds requirements for biodiversity and more sustainable crop production methods. CRIWM helps in maintaining the needed biodiversity as it focuses to match crop production with conservation of biological resources and the development of more sustainable agri-food systems.

## CONCLUSIONS

Improving global food and nutrition security and alleviating poverty is possible only through need based agricultural innovation. The key challenge for common global future will be to grow food sustainably—meeting the demands of a growing population without degrading our natural resource base and associated environment. The adoption of appropriate technologies would substantially increase food production, and improve food security, even under climate change conditions (Rosegrant *et al.* 2014). Sincere efforts need to be made to develop sustainable CRIWM to include them as a component of improved agricultural technologies intended to protect crops from biotic and abiotic stress, alleviate the global food crisis, and ensure food and nutrition security.

Weed management as an integral part of agricultural production needs to move away from its mono-disciplinary perspective at targeting weeds to multidisciplinary and multifaceted technological solution to serve as a component of overall technological solutions to improve agricultural production for achieving ever increasing food and nutritional security challenges. The future weed management technologies that are being invented and adopted will also have much greater impact on global agricultural production, food consumption, food security, and environmental quality. Hence, they should target at agricultural transformation aimed at an eco-efficient revolution with increases in the efficiency of scarce resources used to meet the food demands of increasing population while minimizing many negative environmental impacts associated with current agri-food systems (Rao *et al.* 2017, Rao 2022). Food and nutrition security can be achieved by developing and using knowledge of the best CRIWM practices based on interdisciplinary inputs. The component technologies of CRIWM, prior to their use by farming community, have to be well chosen and be fine-tuned for location specific needs of farming community.

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