Review

Reviving horizontal area expansion of sunflower (*Helianthus annuus* L.) in rice fallow ecosystems - a relook

KULASEKARAN RAMESH, ANITA MAHAPATRA[1], AVIJIT ROY[2] AND SURYANARAYANA BHASKAR[3]

ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad-500 030, Telangana

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ABSTRACT

Rice is cultivated during *kharif* season in Southeast Asia, but a large chunk remains uncultivated or left fallow in the subsequent season due to several reasons, the major being the water scarcity. Sunflower is cultivated in these rice fallows in the states of Karnataka, Andhra Pradesh, Telangana, Odisha, and West Bengal and to a limited extent in other states. This is an opportunity for horizontal expansion of sunflower area to increase the edible oil production in the country. The initial spurt in area since 1970-71 has experienced a sharp decline in spite of sunflower being one of the most preferred edible oils in the rural, urban and peri-urban households. Unlike the popular *utera* method for pulses, sunflower cultivation needs special attention. Concerted and focused research efforts are needed for fine-tuning the production technology of sunflower under rice fallow. The recent success stories of co-culturing honey bee with sunflower as a community initiative in Nizamabad district of Telangana state need to be extended to other sunflower growing regions of the country. This review critically appraises the rice fallow environments in general, determinants of sunflower production in this fragile eco-system and efforts needed for successful area-cum-production growth of sunflower crop in the country.

Keywords: Drought stress, Low land rice, Microclimate, Rice fallow, Rice stubble, Sunflower, Zero tillage

In order to cope-up with the current consumption level of 19 kg of edible oil per person per year, actual demand is pegged at 25 million tonnes of edible oils, of which 10.50 million tonnes is met from primary (soybean, rapeseed-mustard, groundnut, sunflower, safflower and niger) and secondary sources (oil palm, coconut, rice bran, cotton seed and tree borne oilseeds) and the rest 60%, is met through import i.e. 15 million tonnes (Ministry of Commerce & Industry, 2020). With the rise in edible oil demand and change in oil consumption behaviour which is ostensibly the income elastic, import of edible oil has reached 174% during 2010-20 (www.nfsm.gov.in) and could further escalate. Among the various edible oils imported to India, sunflower oil stood third after palm and soya oils with a share of about 60%, 25% and 12% respectively and contributes to one fifth of the edible oil import basket. The import of crude sunflower oil stood at ₹ 13655 crores during 2018-19 (www.agricoop.gov.in). To cope up with the increasing *per capita* demand of edible oils, horizontal expansion of oilseeds in rice fallows is one of the suitable options. Sunflower is preferred by households due to its attractive colour, and fatty acid profile, and considered as a functional food. The crop is native to America and has spread its roots throughout the world particularly the Eastern Europe and Argentina which together share one-tenth of the world's sunflower production (Adeleke and Babalola, 2020) in the past decades due to its versatile nature for cultivation, particularly its photo-insensitivity (Vasudevan *et al.,* 1998) making it amenable for cultivation throughout the year.

As the majority of the area under oilseeds cultivation is still rainfed (around 75%), there is a significant impact of vagaries of monsoon particularly moisture-deficit stress on the productivity of sunflower during most parts its growing cycle and under rice fallows as well. The strategy for horizontal expansion of sunflower area has zeroed-in on the rice fallow environments, if the constraints are tackled systematically.

Sunflower was first cultivated in the southern part of the country to improve oilseed production in 1970's particularly in Andhra Pradesh, Tamil Nadu and Karnataka. The area under sunflower increased from 1.17 lakh ha in 1970-71 to 2.12 lakh ha in 1995-96, and thereafter the area started dwindling ostensibly due to competitive crops. Within a span of a decade (1970-80) only Karnataka could maintain a steady increase in its area while in Andhra Pradesh and Tamil Nadu sunflower area was declining. In the late 1990s, Karnataka's share to all India was about 38.4 to 45.7 per cent and has risen to 61 per cent in 2005-06 (Singha *et al*., 2014). In Odisha, sunflower is grown on 20000 hectares with a productivity of 1185 kg/ha (GoI, 2017). Karnataka, Odisha and Bihar are the three largest sunflower producing states of the country during 2019-20 (GoI, 2021). Notwithstanding these facts, sunflower area in the country has shrunk to 3 lakh ha in 2020-21.

Rice fallows - a golden opportunity for sunflower area expansion: Rice is cultivated during the *kharif* season in Southeast Asia, but a large chunk of this area (15 million ha) remains uncultivated or left as fallow in the subsequent *rabi*

[1]OUAT, Bhubaneshwar-751 003, Odisha;
[2]AICRP (Sunflower), KVK, Nimpith-743 338 (West Bengal);
[3]ICAR-Krishi Anusandhan Bhavan-II, New Delhi-110 012;
*Corresponding author's E-mail: k.ramesh@icar.gov.in

or post-rainy season, due to water scarcity (Subbarao *et al*., 2001; Singh *et al*., 2019). This land is regarded as paddy fallow. Of the total paddy fallow area in South and Southeast Asia, about 44 million hectares is in the country (Kumar *et al*., 2018), with a share of 30% area (11.65 million ha) under *kharif* fallow (NAAS, 2013). In addition to this area, there is one more paddy fallow under either paddy-paddy-fallow (summer) or Paddy-fallow (summer), where in the former two paddy crops are taken up in the system with short-medium duration rice cultivars, while in the latter only one medium duration rice coinciding with the post monsoon or northeast monsoon is taken up (Ramesh *et al*., 2019). The National food security mission in its status paper on rice (https://nfsm.gov.in/StatusPaper/Rice2016.pdf) has broadly grouped rice growing regions in the country into five categories (Table 1).

Table 1 Categories of rice growing regions in India

Region	States and preferably the total area	Main season for rice	Condition	Cropping pattern (single/double/triple)	Projected available area for rice fallow crops in the region	Remarks
North-East	Assam, Manipur, Tripura, Megalaya, Mizoram, Nagaland, Arunachal Pradesh	Feb-Jul, Jun-Dec and Dec-Jun	Rainfed	Single	10.42 lakh ha in Assam (Anon 2018)	Basin of Brahmaputra river.
East	Bihar, Chhattisgarh,Jharkhand, Madhya Pradesh, Odisha, Eastern Uttar Pradesh and West Bengal	May-Oct, Jun-Dec or Jan-Jun	Rainfed	Single	3 lakh ha in Bihar, 28.56 lakh ha in Chhattisgarh, 4.75 lakh ha in Jharkhand, 12 lakh ha in West Bengal (Anonymous 2018) 12.2 lakh ha in Odisha (Jagadev *et al*., 2016)	Basins of Ganga and Mahanadi rivers and has the highest intensity of rice cultivation in the country
North	Haryana, Punjab, Western Uttar Pradesh, Uttarakhand, Himachal Pradesh, and Jammu and Kashmir	May-Nov or Apr-Dec	Rainfed	Single	-	Single crop of rice due to severe winter
West	Gujarat, Maharashtra and Rajasthan	Jun-Dec	Rainfed	Single	-	Rainfed rice
South	Andhra Pradesh, Telangana, Karnataka, Kerala and Tamil Nadu	Mar-Aug	Irrigated/rainfed	Single/ double	14.01 lakh ha in Telangana (Reddy and Reddy, 2017)	Deltaic tracts of Godavari, Krishna and Cauvery rivers and the non-deltaic areas of Tamil Nadu and Andhra Pradesh under irrigated condition in deltaic tracts

North-Eastern region and Eastern region together contribute more than 80 per cent of the paddy fallow area covering the states of Assam, Bihar, Chhattisgarh, Madhya Pradesh, Odisha and West Bengal (Rao *et al.,* 2008). It has also been estimated that rice covering an area of about 26.0 million ha and accounting for 63.3% of the total rice acreage during the *kharif* is available in the Eastern India. Out of which, ~11.7 million ha area remains as rice fallow during the succeeding winter season due to several limitations (Kumar *et al.,* 2019a) in terms of weather and lack of irrigation, etc. In the mono-cropped rice fallows of Odisha (Nayak *et al.,* 2019), sunflower is a preferred crop which occupies 25,000 ha (Mahapatra *et al.,* 2020) and is emerging as an important oilseed crop of the state (Mahapatra *et al.,* 2021a). In the northern region crops which can tolerate chilling injury would fit into this fallow. Sunflower can be a successful crop in the spring season as a sequential crop in the rice-fallow-sunflower cropping system. While western region has limited scope for expansion of sunflower, southern region is the core belt for rice fallow oilseeds *viz.,* sesame and sunflower, to name a few.

Single and double crop rice ecologies: While most of the rice is grown in the *kharif* (wet-season, July-December) as a rainfed crop, rice is also grown in the *rabi* (dry-season, January-June) in many states of India. Approximately 55 per cent of India's rice crop is irrigated (Deep *et al.,* 2018) and majority of these soils is categorized as heavy (clay or clay loams). Such soils, with high water-holding capacity, produce higher rice yields and are suitable for a second crop (Pande *et al.,* 2012). Other than this, alluvial, red, laterite and lateritic, black, saline and alkaline, and peaty and marshy soils are other dominant soil types in which rice is grown (Raychaudhuri *et al.,* 1963) whose utilization by growing oilseeds is basically management driven and the selection of crop and the irrigation infrastructure are the crucial elements.

In Tamil Nadu, the rice fallow is concentrated in the Cauvery deltaic zone as a result of single cropped medium duration rice (Season: Samba; Sowing/planting in August)) and double cropped short duration rice (Season: kuruvai (sowing/planting during June-July) - thaladi/late samba (sowing/planting during September-October) culture. The harvest of samba and thaladi seasons rice falls during January first fortnight to facilitate sowing of rice fallow crops around mid of January (Ramesh *et al.,* 2019).

In coastal Andhra Pradesh, covering the districts of Srikakulam, Vijayanagaram and Visakhapatnam, after long duration rice (140-150 days) which is harvested during November-January depending on the onset of the southwest monsoon the lands are left fallow. Floods are common in this rice culture and hence, flood tolerant rice varieties are preferred in this region. Similar situation prevails in parts of Odisha too. At the time of harvest of rice, the atmospheric temperature remains below 15°C and environmental stress dictates the dates of sowing of sunflower crop as it germinates best at a soil temperature of 21 to 29°C. Temperature and light conditions are very critical for sunflower production (Kingra *et al.,* 2007).

While the residual soil moisture in rice fallow systems endows ample opportunities for expanding oilseeds in this area, lack of provision for a few supplemental irrigations is the key constraint. Cultivation of early to medium duration varieties of rice (Behera *et al.,* 2014) during the *rabi* season to enable farmers grow sunflower on residual moisture in time is a felt need and being short duration in nature, sunflower is an ideal crop for cultivation in the rice fallows.

The rice-fallow soil dynamics: Rice grows under flooded conditions during part or throughout crop growth period. This method of cultivation involves land preparation by puddling followed by transplanting rice seedlings into the puddled soils, and growing of rice in submerged condition until two to three weeks prior to the harvest of the crop (Sahrawat, 2012).

When the soil remains flooded for almost one-fourth of a year in a low land rice-based cropping system, the soil chemistry and microbiology are modified. Flooded soils are devoid of oxygen and two distinct soil layers *viz.,* aerobic top layer and an underlying reduced or anaerobic layer (Reddy, 1982) are formed. This is to tailor the needs of the low land rice crop through modification of the soil redox potential, physical properties and nutrient sources for the soil micro flora. A conservative estimate (Patrick and Reddy, 1976) established that one-fourth of applied nitrogen may be carried forward to the succeeding crop as a residual soil fertility. To be very precise, a considerable portion of applied nitrogen fertilizer to rice system (24.2 to 27.1 kg/ha) remains in the rice soil. In India, the rice crop is fertilized @ 100-150 kg N/ha depending upon the region, soil and other local conditions. Buresh *et al.* (1989) have confirmed that a significant portion of accumulated soil NO_3 may be lost from rice fallows upon the flooding of aerobic soil for rice production. When the flooded rice completes the life cycle, organic and NH_4-N could dominate in the soil over NO_3. Upon fallowing, transmission of aerobic N occurs and NO_3 starts accumulating which might be utilized by the fallow sunflower crop. In the rice fallows, unlike leguminous crops and other oilseeds (Bhaskar and Shivashankar, 1993) sunflower demands additional nutrients to be applied to reap the potential yields and to be remunerative eg. The state of Odisha (Mahapatra *et al*., 2021b).

Ecological considerations for cropping in the rice fallow: Negligible attention has been paid for the utilisation of rice fallows, both in terms of environmental effects and economic value with the sole exception of raising pulses like chickpea, black gram and green gram in the eastern and southern regions as discussed above. Rice fallow systems can have high global warming potential as it emits a lot of N_2O than cropped field (Verma *et al.,* 2006), an issue needing urgent attention for protecting the environment. In the temperate zones of Korea and Japan (Haque *et al.,* 2015), mono paddy cropping systems contribute approximately 30-60 per cent of the annual net global warming potential expressed in terms of greenhouse gas emissions. In these places, paddy fields remain flooded for over 100 days and later they remain fallow under aerobic conditions for over 200 days. Similar analogy may partially hold good for rice belts of Tamil Nadu, Andhra Pradesh and Odisha as well (Ramesh *et al.,* 2019). It has been confirmed that yield-scaled greenhouse gases (YSGHG) emission was highest for rice-fallow-fallow system in West Bengal which can be reduced if the land is properly utilized by making a good trade-off between system productivity and global warming potential GWP through sunflower cultivation in the rice fallows as it registered the highest specific energy and the lowest emission of CO_2 (Ray *et al*., 2020).

Rice fallow sunflower and rice-sunflower cropping systems: Rice fallows are those lands either middle lands or uplands of *kharif* or *rabi* sown rice areas which remained uncropped for the rest of the year as a fallow. Ghosh *et al.* (2012) reported an area of 11.7 m ha after *kharif* rice as fallow in the subsequent *rabi.* In parts of Andhra Pradesh, Telangana and West Bengal, sunflower is raised as a rice fallow crop in a rice-sunflower cropping sequence under zero tillage. In rice fallow sunflower, there is negligible fallow period whereas in rice-sunflower cropping system, the land is thoroughly prepared after rice and the length of the fallow period depends on the local agro-meteorological conditions. Unlike the broadcasting of pulse seeds in the standing rice crop, sunflower cannot be sown in the standing rice crop and needs to be dibbled either manually or mechanically. Sowing sunflower as a sequential crop in rice fallows of Telangana region of Andhra Pradesh (Kumar *et al.,* 2005) or as a zero tillage fallow crop in a clay loam soil at Warangal (Reddy *et al.,* 2010) and sandy loam soils at Bhubaneswar (Patel *et al.,* 2020) was profitable. Practically farmers cultivate sunflower either as a rice fallow crop with zero tillage and rice follow crop with conventional tillage to facilitate sowing and other operations. The interaction of harvesting time of rainy season rice, field moisture condition and temperature at or after harvest of rice determines the success of sunflower.

Determinants of sunflower production

Ecological determinants: Puddling for rice and its effect on the succeeding sunflower: The extensive use of heavy machinery in rice farming brings about numerous benefits through the creation of a compact soil layer particularly to arrest the water loss through percolation and this could have a mixed reactions on the subsequent sunflower in general depending on the soil type. Compaction normally increases the mechanical strength of the soil but excessive use may create soil management problem and can adversely affect plant growth (Raghavan *et al.,* 1977) through tillage and wheel- traffic, that results in a dense soil with poor internal drainage (Bayhan *et al.,* 2002). As a drought tolerant deep rooted crop, in sunflower (Connor and Hall, 1997), the presence of denser soil layers that can reduce both water infiltration in the deeper layers and rooting capacity is against sunflower. It is noted that the inherent characteristics of sunflower *viz.*, deep root system, ability to utilize the moisture from deeper soil layers make it an ideal crop in the fallows (Umesh *et al.,* 2020). A decrease in the soil porosity after mechanical operations (Silva *et al.,* 2008) is a common phenomenon.

In the early growth phase of sunflower, soil compaction affected leaf expansion with an impaired leaf area development through slower expansion rates and smaller size of individual leaves (Andrade *et al.,* 1993) wherever zero tillage was practiced for sunflower. The compacted soil could result in sink-limitation with regard to water, nitrogen, and carbon supply modulated by hormonal signals from the roots. Bahyan *et al.* (2002) noticed a decrease in sunflower yield by negatively affecting vegetative growth. Sunflower may suffer due to very poor root penetration (Aboudrare *et al.,* 2006) and to withstand stress conditions (Skoric, 2009). In sunflower, a decrease in root length, root surface, root volume, and root average diameter with a change in root architecture (Scheiner *et al.,* 2012), a reduction of 55% of root length, 67% of root surface, and 42% of root diameter resulting in a decrease of deep root expansion and in an increased lateral growth (Mirleau-Thebaud *et al.,* 2017) was noticed as a result of soil compaction. However, the soil type had a definite bearing on these issues. Since root elongation rate is dependent on the temperature and intercepted photosynthetic photon flux density (Aguirrezabal and Tardieu, 1996), response to available soil water located below the normal rooting depth (Halvorson *et al.,* 1999) is an important criterion for rice fallow sunflower. In contrast to the above, Sessiz *et al.* (2008) could not find any noticeable impact on sunflower for soil compaction in a clay loam soil. Due to soil compaction from the puddled rice, porosity and lack of good drainage system, sunflower could only have limited root distribution especially as shallow root system in rice fallow soils.

Atmospheric temperature: As a rice fallow crop, sunflower is sown during the winter following rice harvest. To utilise the residual nutrients and utilising the moisture after rice harvest, sunflower needs to be seeded in cold, wet soil immediately after rice harvest. The speed of germination is a factor of soil temperature, moisture and oxygen. Grains Research and Development Corporation (GRDC, 2017) has prescribed a soil temperature of 10-12ºC, for satisfactory germination. Under the rice fallow environments of Andhra Pradesh and Odisha, it is predicted that planting into cold soil temperatures may take longer for germination and establishment unless supplemented with irrigation water. It should be kept in mind that the emergence of leaves for any temperature was linear with time in sunflower (Villalobos and Ritchie, 1992). Undisturbed rice stubbles of varying heights under rice fallow systems depending on the height of rice harvest could modify the soil surface characteristics (Cutforth and McConkey, 1997) and the microclimate as well (Bandyopadhyaya *et al.,* 2016). In the northeast India, rice is harvested by leaving at least 1/3rd to 2/3rd of the stem as standing stubbles in the field (Das *et al.,* 2012). Any intervention to modify the microclimate of emerging sunflower would prove beneficial for the crop establishment.

Poor moisture availability, anaerobic conditions and/or drought: Sowing of sunflower seed (dibbling) at optimum soil moisture content in rice fallow fields particularly in the uppermost layer is important since seedling establishment and maintenance of plant population are limiting factors compared to the total soil water content at planting for the yield (Aboudrare *et al.,* 2006). Excess soil moisture content can cause anaerobic environment for seed germination. During the *kharif* season, water table is generally high but as the monsoon rains withdraw, the water table recedes very fast. Even if the crop gets established well by utilizing available soil moisture, lack of winter showers towards flowering stage may create drought conditions leading to crop failure (Kumar *et al.,* 2018). Low moisture content in the soil after rice harvest, fast receding of water table with the advancement of retreating monsoon, and risk of intermittent soil moisture stress towards seed filling stage are a few other constraints for the optimum productivity of fallow crop of sunflower.

Production determinants

Genotype: Sunflower is non- photosensitive which ensures cultivation round the year. Genotypes bred for a particular season may not perform satisfactorily under rice fallow. For eg. KBSH 53 yielded 2161 kg/ha during *kharif* while under rice fallow 1521 kg/ha only at Bengaluru (Sujatha *et al.,* 2016). In most of the states, varieties recommended for non-fallow conditions are cultivated in the rice fallow too. Sunflower is highly sensitive to water logging and a clear relationship has been established (Orchard and Jessop, 1984) between duration of waterlogging and yield, and hence water tolerant strains need to be bred. Notwithstanding this, with respect to yield stage of development seemed to be the key determinant than the duration of waterlogging (Orchard and Jessop, 1984).

The second criterion with regard to genotype is the short duration to escape the unexpected moisture stress at the maturity stage. Notwithstanding this concern, duration need not necessarily be the sole criteria for selection of genotype for rice fallows, instead a genotype with robust root system to extract water from lower layers is equally important. In a typical lowland rice-growing area, Kumar *et al.* (2019b) noticed a fast receding soil moisture in the top 30 cm soil. The deeper soil layers are usually endowed with sufficient soil water. Hence root: shoot ratio can also be considered as an important criteria for recommending of sunflower hybrids for rice fallow ecologies.

The third criterion would be the weed competitive genotype to suppress the weeds since chemical weed management in rice fallows are seldom carried out. In general, weeds have a competitive advantage especially during the initial stages of crop establishment over sunflower in rice fallow due to available soil moisture. Once the sunflower crop gets established, the leaf area covers the ground area and deprives sunlight to the broadleaved weeds.

Nutrient management: Rice fallow technologies have been promoted as, inter alia, banking of the stored soil moisture and the residual nutrients from rice crop. As an oilseed crop, sunflower demands all essential nutrients for optimum production. Wherever, sunflower is sown in rice fallows, the crop is sub optimally fertilized, and consequently the crop suffers due to nutrient stress. Sulphur is an important element for rice fallow oilseeds (Bhaskar *et al.,* 2000) besides other nutrients. Experiments at various AICRP sunflower centres over the past few years have indicated that the rice fallow sunflower crop irrespective of the tillage regime demands more than the blanket recommendation for non-rice fallow crop of sunflower (Meena *et al.,* 2021). In an irrigated well managed lowland rice field with grain yields of 5 to 7 t/ha, fertilizer recovery efficiencies are 30 to 60 per cent, 35 per cent and 15 to 65 per cent for N, P and K (BCI, 2002) implying that the residual nutrients will remain in the soil for utilisation by the succeeding crop. In order to produce 1 tonne of paddy (rough rice), the rice crop absorbs an average of 20 kg N, 11 kg P_2O_5, 30 kg K_2O, 3 kg S, 7 kg Ca, 3 kg Mg, 675 g Mn, 150 g Fe, 40 g Zn, 18 g Cu, 15 g B, 2 g Mo and 52 kg Si (Roy *et al.,* 2006a). The results of long-term fertilizer experiments conducted with rice-based cropping system at several stations confirm the inadequate nature of so-called 'optimum' fertilizer recommendations (Tiwari, 2002).There exists variation between the amounts of nutrients removed by the upland rice cultivar, and in decreasing order it is N >K > Mg > Ca > P > Fe > Mn > Zn, whereas for the lowland rice cultivar it is K > N > Mg > Ca > P > Mn > Fe > Zn (Sahrawat, 2000) which could determine the nutrient management in the succeeding sunflower crop in turn. The nitrogen lost through ammonia volatilization, runoff, and leaching from the paddy field was 37.2 to 102 kg N/ha, with ammonia volatilization accounting for 69.6% to 83.5% of nitrogen loss (Yang *et al.,* 2013), of which there exists a possibility that the unutilized N leaches to much deeper soil layers as part of the unutilized N (Nishikawa *et al.,* 2014) and that will be available for use by the succeeding crop. But this needs to be quantified for sunflower. This is in jeopardy, if hard pan develops during rice puddling which makes sunflower only a surface feeder.

Removal of straw from the field is widespread in India and hence the depletion of soil K and Si reserves, which has a significant impact on the succeeding fallow crop. In the process, some or all of the nutrients contained in straw may be lost from the rice field (Dobermann and Fairhurst, 2002). In order to produce 1 tonne of yield the sunflower crop absorbs an average of 63.3 kg N, 19.1 kg P_2O_5, 126 kg K_2O, 11.7 kg S, 68.3 kg Ca, 26.7 kg Mg (Roy *et al.,* 2006b). As the fallow sunflower crop is cultivated with minimal nutrient inputs, the nutrient management in rice would have a definite impact on the succeeding sunflower. Sulphur is another important nutrient for sunflower (Veeranagappa *et al.,* 2015) but ignored in fertilizer regimen. Further, the physical condition of soil is poor due to puddled rice and consequently nutrient mobilization is reduced. Zero tillage fertilized with 150% RDF (90:120:90 kg N: P_2O_5: K_2O/ha) could maximize productivity of sunflower hybrid under rice fallow environments of sandy loam soils of Odisha (Mahapatra *et al.,* 2021b). Thus, it is understood that sunflower needs to be fertilised even higher than the RDF for realising optimum productivity (Kalyani *et al.,* 2020). Umesh *et al.* (2020) have confirmed that rice fallow sunflower needs a fertiliser dose of 135:135: 90 kg N: P_2O_5: K_2O/ha, 50% higher than the recommended dose.

Water management

Excess water/flooding: Despite water being a critical ingredient for production, excess water during the crop growing season can result in significant negative effects on crop yield of sunflower. Therefore, water management is very crucial for sunflower as a rice fallow crop since poor water management results in waterlogging at the establishment stage and hampers the establishment, growth and yield of sunflower severely by reducing the availability of oxygen and increased ethylene concentrations in the soil (Yasumoto *et al.,* 2011). Water logging is also known to reduce the root growth leading to other physiological effects (Orchard and So, 1985) besides rapid ethanol synthesis in the roots (Jayasekera *et al.,* 1989). Ultimately, this reduces photosynthesis (Wample and Davis, 1983; Wample and Thornton, 1984) either due to stomatal and/or non-stomatal limitations (Ben *et al.,* 1987; Jayasekera and Boyer, 1990). Short term waterlogging (Orchard and Jessop, 1984; Orchard and So, 1985; Orchard *et al.,* 1986; Jayasekera *et al.* 1989) is widespread in rice fallow sunflower regions (Grassini *et al.* 2007), if not long-term water logging. Although sunflower possess the ability to adapt to waterlogging (Orchard and Jessop, 1984), waterlogging during anthesis (Orchard and Jessop, 1984) and grain filling stages (Grassini *et al.,* 2007) are detrimental than the vegetative stage as it inhibits only leaf expansion (Orchard *et al.,* 1986).

Water stress/drought: While excess water as discussed in the previous section is essentially due to poor water management practices, water stress is conjoint in rice fallow sunflower regions in the country. As a dry season crop of the world, sunflower can resist short periods of water deficit (d' Andria *et al.,* 1995) without noticeable yield penalty with a rider on the stage of water stress (Unger, 1982; Keipp *et al.,* 2020) as it is relatively tolerant to moisture stress (Killi *et al.,* 2017). Owing to its capability of extracting water from deep layers of soil (Chiaranda and Andria, 1994), Rauf (2008) classified sunflower as a low to medium drought sensitive crop making it a suitable candidate for rice fallow since water stress of varying magnitude is very common under these conditions. However, it becomes a yield limiting factor (Ravishankar *et al.,* 1991; Hussain *et al.,* 2017). A reduction in leaf water potential in drought-stressed sunflower plants with increased leaf resistance was noticed by Wample and Thornton (1984) besides photosynthesis. Interestingly, Nezami *et al.* (2008) observed that drought from 4-leaf- stage up to the end of plant growth period did not interfere with leaf production.

Mechanisation related constraints

The efficiency of manual harvesting system by using sickle is a whopping 180 and 200 man hours per hectare to harvest rice (Pande and Devnani, 1984). In the Asian countries, like India, China, Thailand, Vietnam and even in Cambodia the use of combine harvester for paddy harvest is increasing very rapidly to tide over the labour shortage for harvesting of rice which has the multiple advantages and economically attractive. This combines several operations at one go *viz.,* cutting the crop at a desired height from the ground, feeding it into threshing machine, threshing, cleaning, winnowing and transferring directly into a bag with an average post harvesting losses of only about 2.96 per cent of rice yield (Sharanakumar, 2011). This mechanisation although lucrative to rice farmers, the subsequent crop in the sequence faces the onslaught particularly due to excess soil compaction as the normal weight of self-propelled combine harvester is 8200 kg (farmech.dac.gov.in). The compaction is a looming threat for the utilisation of zero tillage rice fallow sunflower.

Opportunities for sunflower cultivation in the rice fallow regions: Opportunities for the successful cultivation of sunflower in the rice fallow with minimal investment need to be explored, particularly where a couple of supplemental irrigations are assured so that optimum yields could be realized. Many growers are reluctant to switch to sunflower in rice fallow because they perceive alternate crops as being more cost-effective despite growing evidence that sunflower can improve profitability as observed in the states of Telangana, West Bengal and Odisha. In spite of the issues stated earlier, the unique adaptation of sunflower to different climatic and soil conditions (Forleo *et al.*, 2018) enhanced its suitability across rice fallow regimes of the country. However, the following research issues needs attention.

Macro level planning

Mapping of rice fallow areas: The information on rice fallow areas are scattered and needs to be consolidated for accurate estimation. The available rice fallow area from various agencies provide only some preliminary information. National Mission on Oilseeds and Oil Palm has also made efforts for bringing additional area under rice fallow with pulses and oilseeds and sunflower is one among the targeted crops. Gumma *et al.* (2016) have estimated that approximately 22.3 M ha of rice-fallow is in South Asia of which 88.3% is in India. Since the fast depletion of the soil residual moisture is the primary obstacle for rice fallow crop (Kumar et al., 2019a), recently the Government of India has made efforts to map the rice fallow areas of the country with satellite image with due consideration to soil water status from Mahalanobis National Crop Forecast Centre, New Delhi under National Food Security Mission.

Success models of rice fallow in selected states: In West Bengal, sunflower is second important oilseed crop after rapeseed-mustard during rabi season. Particularly in Sunderban area, farmers raise sunflower crop as a rabi-summer crop after the harvest of flooded paddy. As the main season autumn rice is harvested during October-November, November 30 sowing date was identified to be ideal for sunflower for getting maximum yield under Gangetic West Bengal condition (Dutta, 2011). The predominant rapeseed-mustard area has shrunken due to short winter spell, delayed sowing and infestation of pest and diseases (Dutta, 2015) and sunflower has wide scope in the state overriding the competing crops mungbean and bhindi. Several farmer groups have modified their land configuration into 3-4 rows of sunflower in a paired row for managing irrigation for sunflower and save irrigation water and labour (Ramesh *et al.,* 2018). Few innovators have initiated village level oil extraction to make the sunflower farming a viable business model.

The relatively short duration with drought tolerance made it a potential crop with limited irrigation water availability (Swain *et al.,* 2019) in Odisha. More and more farmers in Dhenkanal district of Odisha are taking up sunflower cultivation in the wake of frequent depredation of crops by elephants, besides the perennial threats of flood and drought over traditional paddy cultivation in most of coastal Bhadrak district to switch over to sunflower. In the recent past, Begunia block, Khurda district of Odisha has increased the area under rice fallow sesame.

The success of rice fallow sunflower in Nizamabad district of Telangana is linked to water availability in the region. If there is in adequate supply of water for cultivation of second season rice, rice fallow sunflower could occupy major chunk of rice fallow area.

Micro level planning

Conservation agriculture practices: A careful analysis of opportunities for horizontal area expansion of oilseeds has zeroed-in on moisture conservation/resource conservation technologies. It has been acknowledged that zero tillage concept has a wide scope to harness full potential of rice fallow sunflower considering the need to conserve the soil moisture and nutrients. Conservation tillage implies a shift away from strict reliance on control of existing tillage practices and places greater emphasis on environment, soil organic carbon storage, minimizing tillage expenses and so on. Selective rice fallow regime needs an appropriate conservation tillage coupled with fertiliser schedule for a suitable hybrid. This decision making framework, would result in a greater level of productivity with high economic benefit than de facto package of practices for non-rice fallow systems. However, tillage in general had more positive effect on seedling emergence, growth and yield of sunflower than a zero tillage in puddle rice fallows in a sandy clay loam soil (Typic Haplustalf) at Hyderabad (Gurumurthy *et al.,* 2008). Hence conservation agriculture practice are soil and location specific and can't be generalised.

Supplementary irrigation: No matter when the sowing of sunflower as a rice fallow crop is taken up, yield improvement relies heavily on two tactics, the nutrient and irrigation management, of which the lifesaving irrigation at critical crop growth phase, particularly flowering period, is critical. Other water requiring phases are pre-sowing, 20 days after sowing, early bud development, flowering- and seed development.

Co-culturing of honey bees with sunflower: Co-culturing of honey bees with sunflower as a community initiative in the Nizamabad district of Telangana has opened new avenues for the sunflower growers. The erstwhile recommendation of keeping of 4-5 honey bee hives/ha in the sunflower fields to facilitate bee pollination has several pitfalls due to migration of bees during lean period. Hence, the new initiative by a commercial honey entrepreneur wherein several dozens of bee hives are maintained in a particular field to collect honey from the surrounding 2-3 km radius has paid dividends and has to be promoted as a community initiative. This has the twin benefits of honey production as well as enhanced pollination for sunflower productivity.

Research gaps: Despite significant advancements in understanding the agro-meteorology of sunflower at production systems, there remain significant gaps in understanding the relationships between climatic variability and crop yields at finer spatial and temporal scales as the sowing time under rice fallow is a function of the duration of the preceding rice crop. High yielding genotypes of sunflower are too few for cultivation under rice fallow. Research on sunflower genotypes specific to rice fallows, low temperature tolerant and, water logging tolerant strains are needed in addition to drought tolerant cultivars to withstand moisture stress at later stages of crop growth. Besides research with respect to developing suitable genotypes, information on soil health, pest management, mechanization, etc. are also needed. Notwithstanding these issues, a rapid expansion in the sunflower area is on the rise in the states of Telangana, Odisha and West Bengal as a rice fallow crop since availability of water is a serious limitation for the competing vegetable crops.

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