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**Review paper**

# Precision water management in pulses for enhanced resource-use-efficiency

CS Praharaj[1*], Narendra Kumar[2], Ummed Singh[3] and CP Nath[2]

[1]*ICAR-Directorate of Groundnut Research, Junagadh - 362 001, Gujarat, India*
[2]*ICAR-Indian Institute of Pulses Research, Kanpur - 208 024, Uttar Pradesh, India*
[3]*Rajasthan Agricultural Research Institute, Gurgapura, Jaipur – 302 018, Rajsathan, India*

[*] ***E-mail:*** *cspraharaj@hotmail.com*

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*Dr. KK Hazra, ICAR-Indian Institute of Pulses Research, Kanpur, India*

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## ABSTRACT

**Although greater efforts have been made to realize higher yields with desired quality from a number of high-yielding varieties of pulses with matching agro-technologies and proven tolerance to biotic/abiotic stresses, yet there has been a shortfall (though minimized to a greater extent now) in expected goals in production/productivity in these field crops. Therefore, there is a need for renewed and innovative approach for sustainable cropping intensification with pulses. In this context, water–a critical input for sustained crop production – is becoming limiting both under rainfed and irrigated conditions depending on its availability, competing factors, allocation to priority crops, and season of the year. It deserves all of us to use this precious commodity more judiciously, sensibly and need-based in agriculture through modern technology, especially in presence of diverse constraints. One of the approach for effective on-farm management of water is its precision use. One or two life-saving/supplementary irrigation through water-saving technologies (drip or sprinkler irrigation) during the post-rainy/ *fall* months or even under dryland condition could sustain productivity of crop. Some of the innovative agro-technologies could reinforce this by way of technology up-scaling and/or providing a sound footing for better water delivery/use. These include precision land levelling, no-till systems, furrow-irrigated raised bed planting, and crop diversification and its residue management. Thus, adaptive strategies for grain legumes or pulses will be highly location-specific and offers an alternative for a quantum jump in its production with sustainable resource management and resource use efficiency (RUE). To conclude, strategic water management in pulses could play a significant role in their sustainable intensification/diversification of already scarce resource-base in time to come (in the context of Sustainable Development Goals).**

***Keywords*****:** Climate change, Precision water management, Pulses, RUE, Water footprint, Water productivity

## INTRODUCTION

Pulses, an important source of dietary protein and calories for vegetarian masses, are generally grown with nominal input in varied environments (NAAS, 2016). Gifted with unique property of fixing atmospheric nitrogen in their root nodule, pulse crops can improve soil chemical properties and maintain soil fertility (Herridge *et al.* 2008). On an average, these groups of crops add up to 40 kg/ ha N to the soil that results in sustainability of system productivity (Praharaj *et al.,* 2016, 2021). Pulse crops are potential source of energy, proteins, carbohydrates, fat, P, Ca, Mg and other minerals. Despite the fact that these are mostly grown as rainfed crop all over India (87%), a majority of N need of these pulses is met from N fixed from air and the rest is left behind in the form of residual N and soil organic matter (SOM) for the use of subsequent crops in rotation (Sharma *et al.*, 1986). Besides this, they are also good sources of the B-group vitamins apart from riboflavin, and are capable of alleviation of increasing protein hunger and malnutrition that is prevalent amongst the poorer section of the society (Kumar *et al.*, 2018, 2019). Thus, pulses play a key role in nutritional security, soil amelioration and sustainable crop production (Ahlawat 2005a, b; Ali and Gupta, 2012).

More than a dozen of different pulse crops are grown for cultivation in India. The commonly grown pulse crops are chickpea (*Cicer arietinum*), pigeonpea (*Cajanus cajan*), urdbean (*Vigna mungo*), mungbean (*Vigna radiata*), horsegram (*Macrotyloma* *boorus*), mothbean (*Vigna aconitifolia*), lathyrus (*Lathyrus sativus*), lentil (*Lens culinaris*), cowpea (*Vigna unguiculata*), drybean (*Phaseolus vulgaris*) and peas (*Pisum sativum*). However, chickpea and pigeonpea are the major pulses, occupying together 61% of the total production of pulses in the country. These crops formed an integral part of the different cropping systems for sustainable agriculture. During the past few decades, the cultivation of pulses has witnessed an unprecedented geographical shift, catalyzed mainly by assured irrigation facilities being available in the IGP, which once used to be the pulse basket of the country till 1970s. The area under pulses in this region was largely replaced by wheat, rice and maize due to assured irrigation facilities. However, reduction in area under pulses was compensated by a proportionate increase in acreage especially in Central and Southern parts of the country. Nevertheless, an aggressive varietal improvement, matching production & protection technology development programmes, and research & policy initiatives have led to development of high yielding, multiple stress resistant and short duration varieties in different pulse crops suitable to different locations/regions/zones/states (Singh *et al.*, 2017, 2020; Ghosh *et al.,* 2020). As a result of these efforts, the APY in pulses reached to 30.7 m ha, 26.96 mt, and 888 kg/ha during 2021-22 (Table 1). Further, impressive growth in pulses production during last decade (4.7%) has led to increase in per capita availability of pulses (55.9 g from 35.4 g per caput in 2010).

**Table 1.** Pulses production trends in India from 2009-10 (DES, 2022)

| Year | Area (m ha) | Production (mt) | Yield (kg/ha) |
|---|---|---|---|
| 2009-10 | 23.28 | 14.66 | 630 |
| 2013-14 | 25.21 | 19.25 | 764 |
| 2017-18 | 29.82 | 25.41 | 853 |
| 2021-22 | 30.73 | 26.96 | 888 |

With rising demand of vegetarian food due to ever-increasing population and diversification of food habits, demand of pulses is swelling at a fast pace. This is further challenged by extreme events under changing climatic scene in the form of shifting rainfall pattern, untimely and erratic rains, extreme temperatures, length of dry period within the monsoon season, occurrence of frost and even initiation and spread of varied biotic stresses. Pre- and post-harvest losses of food legumes are still enormous and needs consideration as it adds to production/buffer stocks in storage. Therefore, production of pulses to be increased and sustained over the time (~38 to 40 million tonnes by 2030 at a growth rate of ~2%) to eradicate large scale protein hunger and malnutrition. Climate change associated (sometimes with water surplus) problems especially with low productivity, particularly under rainfed and dryland conditions/regions is considered as one of the major challenges requiring attention and need to be addressed on priority (Bhadana *et al.,* 2013). It is a fact that the input needs of these pulses are also meagre and that in respect of water is about one-fifth of the requirement of cereals (Table 2). Therefore, there is a strong need to formulate strategies for development of (precision) water management techniques (with pulses as lowest water requiring crops, Table 2), bio-intensification of pulse-based cropping systems, and resource conservation for increased productivity and RUE (Praharaj *et al.,* 2009, 2017; Praharaj *et al.,* 2019, 2020). The details of irrigation management techniques and the innovative practices adopted in different pulses are listed herein as under.

**Table 2.** Water requirements of major food crops

| Crop | Duration (Days) | Water requirement (cm) |
|---|---|---|
| Rice | 100 | 95–100 |
| Ragi | 105 | 45–50 |
| Pulses | 70 | 20–25 |
| Pulses (long duration) | 150–250 | 30–50 |
| Maize | 100 | 40–45 |
| Cotton | 165 | 60–75 |
| Groundnut | 105 | 60–65 |
| Sugarcane | 300 | 225–250 |

Source: Doorenbos and Pruitt (1977)

## SURFACE IRRIGATION

***Winter pulses:*** Irrigation influences crop productivity and input-use efficiency in all the major winter pulses including chickpea and lentils. In chickpea, it is showed that pre-plant irrigation followed by one irrigation at pre-podding stage raised seed yield by 77% over no irrigation (Ali, 2009). Its productivity was increased further by applying irrigation once at 50% flowering/pod-development stage, or two irrigations - one each at branching and pod-development stage - depending on the rainfall (winter rains) received during crop-growth period. On different method and depth of irrigation in the crop, higher grain yield and water-use efficiency (WUE) was obtained with 3.0 cm irrigation water through flood-irrigated flat beds (FIFB) and 1.5 cm in furrow-irrigated raised beds (FIRB). Besides this, raised bed planting yielded higher than flat planting by around 18.8% and conserved more water with enhanced WUE in chickpea (Ali, 2009). Two years' study at the ICAR-IIPR, Kanpur, Uttar Pradesh on Optimum Irrigation Scheduling (OIS) with irrigation applied at branch and pod development (BPD) showed significantly higher grain/biomass yield, harvest index (HI), net returns (NR), benefit : cost ratio (BCR) and productivity/day over others (Praharaj *et al.*, 2017, 2018). As a result, there was an increase in net water saving/WUE (~30%) and WP (~20%) following OIS at BPD over that in flood irrigation at both the stages to realize the same yield levels (2.65 t/ha). Studies in chickpea and pigeonpea (long duration covering both *kharif* and *rabi*) conclude that two irrigations (one each at branching and the other at pod formation) are optimum in central India (Mishra *et al.*, 2012 a,b). In North-West-Plain Zone (NWPZ) and North-East Plain Zone (NEPZ), although response to irrigation is generally low due to adequate winter rains and high relative humidity, yet in absence of rain, 2–4 irrigations could be adequate as per water need of the crop/species and duration of pulse crop concerned (Ali, 2009).

In field pea, 50% flowering stage was the most critical for irrigation (Panwar and Malik, 1977; Panwar, 1979). Similarly, in lentil, one irrigation at the early pod-filling stage coinciding with 55–60 days after sowing was effective as the crop had already received a pre-sowing irrigation especially in case of heavy soils to replenish inadequate soil moisture. This could be supplemented with a raised bed planting for saving 20–25% irrigation water in lentil besides increasing grain yield substantially (Ali, 2009). Similarly, irrigation at both branching and flowering stages resulted in higher grain yields than the control in dwarf peas. Further, in defining the number of irrigation requirement, it showed that three supplementary irrigations at 45 DAS, 50% flowering and pod development could be adequate in absence of winter rains in field peas (Ali, 2009). Similarly, in *rabi* pigeonpea, 3 irrigations at 25, 75 and 100 DAS could maximize its productivity in absence of winter rains and the most important critical stage being 25 days' crop stage for optimum population and realization of optimum yields. Therefore, 3–4 irrigation schedules at required intervals could suffice crop requirement for moisture in these crops.

On evaporation demand-based irrigation scheduling, Irrigation Water : Cumulative Pan Evaporation (IW:CPE) of 0.8 was adequate for realizing optimum yield in fieldpeas and *rabi* Pigeonpea although scheduling of irrigation at 0.4 IW : CPE resulted in the highest yield in *rabi* pigeonpea (Ali, 2009). Frequent irrigation at > 0.6 IW:CPE ratio didn't benefit chickpea crop except for vegetative growth (Yadav, 1975). In addition, use of anti-transpirant (HICO) resulted in significantly higher seed yield (33%) over the control under rainfed condition, although no such improvement was recorded in irrigated condition (Ali, 2009). The combination of tillage and mulch was also beneficial. Deep tillage and cultural mulch recorded 33 and 31.6% higher yield of chickpea than zero tillage alone with 65% higher WUE in the former over that in zero tillage (Ali, 2009). Work on application of water-absorbing polymer '*Jal Shakti*' started at the IIPR during late 1980s revealed that the furrow placement of 2 kg '*Jal Shakti*'/ha improved productivity of chickpea by 12% (Singh, 1988) and was economical.

***Spring and summer pulses*:** Mungbean, a fast growing and remunerative pulse crop with low water requirement in comparison to most of the cereal/ oilseeds crops, has the requisite yield potential in meeting the shortfall in total pulses production in the country. In Northern Plain Zones (IIPR, 2015–16), it was revealed that when this was planted during the last week of March after potato (*Solanum tuberosum* L.)/garlic (*Allium sativum* L.) or winter vegetables, it required only 2 irrigations (due to higher residual soil moisture after March harvested crop) in comparison to normal 4-5 irrigations for later planted crop after wheat/vegetables (with low residual soil moisture during April/May). Further scope for higher yield exists through amalgamation of improved varietal interventions ('Samrat', 'IPM 02-3', 'IPM 99-125', 'SML 134', 'IPM 205-7'), pre- and post-emergence herbicides, precision management in crop cultivation complemented/ supplemented with appropriate micro-irrigation-based irrigation scheduling and suitable land configuration (raised bed/ ridge planting especially during *kharif*), replenishment of nutrients based on soil health cards (SHC) for optimum fertilization including application of Zn, S and Mo (in presence of adequate P and K) and use of suitable machines from planting (IIPR No Till Drill) to harvesting operations/value-addition. The advances in zero tillage for pulses has made possible to reduce the time lag for early sowing of pulses (with additional benefits of uniform drilling of seed and higher fertilizers-use efficiency, water-saving and increasing yields by 20%. Similarly, the importance of no-till system in India is quite evident in terms of greenhouse gas emission and carbon sequestration (Venkatesh *et al.*, 2013). It is estimated that for each litre of diesel fuel consumed, 2.6 kg $CO_2$ is released to the atmosphere. Assuming that 150 litres of fuel is used per ha-year for use of tractor and irrigation in conventional system, it would amount to nearly 400 kg $CO_2$ being emitted per ha-year. Thus, the role of no-tillage/ conservation agriculture in economic growth is gigantic and thus, cann't be undermined (Sangar *et al.*, 2004).

Potential agronomic advantages of FIRB include improved soil structure owing to reduced compaction through controlled trafficking, and reduced waterlogging and timelier machinery operations owing to better surface drainage. Typical irrigation savings range from 18% to 30–50% (Hobbs and Gupta, 2003; Jat *et al.,* 2005a, b). Trials by farmer/ researcher in IGP showed that irrigation water savings of 12 to 60% was accrued for direct-seeded (DSRB) and transplanted (TRB) rice (*Oryza sativa* L.) on beds, with similar or lower yields for TRB compared with puddled flooded transplanted (PTR) rice (Balasubramanian *et al*., 2003). Similarly, raised-bed planting outyielded flat planting and also enhanced both water use and WUE in pulses (Ali, 2009) besides increasing fertiliser-use efficiency (Praharaj *et al.*, 1993).

In the case of crop residue management, decline in SOM due to limited/ reduced return of organic biomass has been identified as one of the key factors for un-sustainability of the system (Praharaj *et al.*, 2009; Singh *et al.,* 2011). Improper crop-residue management (burning) due to inadequate *in-situ* recycling (Jat *et al.,* 2004) not only leads to loss of considerable amount of N, P, K and S but also contributes to the global $NO_2$ and $CO_2$ budget (Grace *et al.,* 2002) and destruction of beneficial micro-flora of the soil as a substantial quantum (80.12 m t per annum) of crop residues is available (Pal *et al*., 2002) for recycling in rice–wheat system. Similarly, use of *cover crop/ crop diversification* (Praharaj *et al*., 2009) improved the stability of CA system. Effect of stubble length of rice or *kharif* crops mitigated soil-moisture stress and grain yield of lentil in a rice–lentil relay system. Thus, short-stubble height (10 cm) could reduce both lentil grain yield and water productivity by 275 kg/ ha and 0.1 kg/$m^3$, respectively, over those in long-stubble (20 cm) height (Bandyopadhyay *et al*., 2016). Thus, less water-requiring pulses like, lentil in rice fallows could sustain yield above national average through saving of energy and time by conserving soil moisture with standing crop residues (Singh *et al.,* 2016, 2017a, b). Moreover, legume intercropping in cereals grown with wider row spacing reduces nitrate leaching through soil cover and conservation of water. This is why CA systems will be the most thrust of the *future farming* (Praharaj *et al*., 2014).

## MICRO-IRRIGATION

Micro-irrigation techniques use precision technologies for efficient management of both water and nutrient precisely near the root-zone of the crop plant. The major advantages in terms of water application include (i) water is applied directly to the root zone of plants and (ii) can be combined with other nutrient/ agrochemicals/ inputs, and (iii) water is applied in frequent intervals in precise quantities as per the crop-water requirement (Chaudhary *et al*., 2005). In fact, water is applied through a low-pressure pipe network comprising mains, sub mains, laterals and emitting devices. In addition, saline water up to 8–10 mmhos/ cm can be used. Fertilizer can be combined with drip water, thus, precision application of water results in lesser weeds and pests and greater pod retention (Ramamurthy *et al.*, 2009). The likely benefits are substantial and these include an array of crop growth and developmental benefits. Micro-irrigation involving drip-fertigation and sprinkler irrigation are also quite effective for on-farm allocation and management of precious water (Chaudhary *et al*., 2005). In the event of acute moisture stress, 1 or 2 irrigations directly applied to root zone of the crops elevates crop performance. Thus, importance of 1 or 2 life-saving irrigations especially at critical stages makes a sense. Hence under the existing agro-ecology, micro-irrigation technology meant for quick and immediate distribution of water delivered near the root zone accompanied with dissolved fertilizer(s) is a boon for both appropriate utilization of water & nutrient and their increased utilization efficiency. Micro-irrigation (*drip and sprinklers)* has also an additional advantage of reduced conveyance losses, ease of portability within the field and near the crop and makes it user friendly. The application of precision or other micro-irrigation in case of pulses especially in wide spaced pigeonpea is still remote and needs a fill up to realize higher farm output and input-use efficiency.

A study conducted under a micro-irrigation management in summer pulses showed that a significant improvement in seed yield (31%) with water saving (11% less water uses and 43.2% enhanced WUE) were recorded in summer mungbean with precision tillage carried out by laser leveller. Sprinkler irrigation was advantageous for enhancing the irrigation efficiency even for 2 months duration of mungbean crop (with 20% less water use and 24% higher WUE) over flood or normal irrigation at podding and seed setting (IIPR, 2014–15). The popular mungbean variety 'Samrat' suffers in hot summer months due to blanket irrigation because of irregular *in-situ* depressions/ponding zones developed in field especially when it was not accompanied by a laser leveller (Praharaj *et al.*, 2015c). Therefore, unevenness of the soil surface influences the farming operations, drudgery involved, energy use, aeration, crop stand and productivity mainly through nutrient-water interactions. Laser-land levelling is also useful especially in intensively cultivated irrigated farming through achieving a better crop stand while saving irrigation water with improved input-use efficiencies. As a result, zero-till seed drill performed better on a well-levelled field compared to unlevelled or fairly-levelled field owing to better seed placement, germination and uniform distribution of irrigation water and plant nutrients (Sankaranarayanan *et al.*, 2008, 2010; Praharaj *et al.*, 2015c). Beneficial role of sprinkler irrigations in the late afternoon/ evening hours in summer/ spring mungbean is also pertinent. Although there was similar yield under sprinkler vs flood irrigation at critical stages (two irrigations – one each at branch and pod), there was significant water economy through micro-irrigation (35– 50%). In addition, farmers' practice of planting at uniform 30-cm-row spacing reduced seed yield to the extent of 16–20% compared to that at 22.5-cm-row spacing owing to better utilization of interspaces and water (IIPR, 2015–16). Besides this, variation in performance of different varieties also exists (10% additional yield was realized under 'Samrat' at 1.23 t/ha over 'IPM 205-7' at 1.12 t/ha when mungbean was sown during the last week of March).

Similar to furrow or flood irrigation, 1–2 irrigations by appropriate micro-irrigation schedules at the most critical stages has proven highly productive in most of the pulses. Drip-fertigation in long-duration pigeonpea at branching & pod development with N and K at one-fourth of recommended dose (of 20 : 20 kg/ha) in 5 splits in the above stages (along with ½ of N and K + full P at sowing) gave higher yield and returns (Praharaj *et al.*, 2016). A case study carried out at the ICAR-IIPR, Kanpur revealed the importance of even a single drip-fertigation scheduling at the most critical stage in pigeonpea is useful with enhanced RUE (Praharaj and Kumar, 2012; Praharaj *et al.*, 2014). Yield attributes such as pods/plant, 100-seed weight and harvest index showed similar trend with that of seed yield. Lower water use, greater profile soil-moisture content and water-use efficiency, higher plant NPK uptake with improved soil nutrient availability and greater net returns were evident with drip fertigation at both the stages (Table 3). Besides pigeonpea, the micro-irrigation benefits have also been extended to other pulses, *viz.*, mungbean, chickpea, lentil, fieldpea and rajmash. However, irrigation should be avoided during active flowering period, otherwise flower shedding and reversion to vegetative growth may occur. Thus, water-saving measures through micro-irrigation could possibly be extended to large areas, enabling efficient management of precious water through community sharing of irrigation infrastructures through village cooperatives and welfare schemes (Praharaj *et al.*, 2014).

Further studies made on drip-fertigation where both water and fertilizer are applied precisely at the root-zone during pick crop demand ensures direct benefit to plants (Ramamurthy *et al.*, 2009). This supplementary irrigation especially during long dry spell after rainy months could possibly alleviate moisture stress in growing crop (Praharaj and Kumar, 2011; Praharaj and Kumar, 2012; Praharaj, 2013). Further restrictions imposed as a result of climatic aberrations in terms of deficiency in rainfall and its diminished frequency/ distribution especially at flower/ pod development can also be alleviated with supplementary irrigation aided with micro-irrigation (Lal, 2004). In other trials involving micro-irrigation (sprinklers), the results obtained were similar.

Similarly, primary studies were conducted on sprinkler irrigation (Chandegara and Yadavendra, 1998) in closely planted short-statured legumes like chickpea and mungbean. It revealed that three sprinkler irrigations of 60 mm each at sowing, branching and pod-formation stages were sufficient for chickpea with a water saving of 44% (Chandegara and Yadavendra, 1998). Sprinkler irrigation in mungbean increased yield by 39.7% over surface irrigation and resulted in water saving of 49.8% (Velayutham and Chandrasekaran, 2002). Thus, there is a need for evaluating existing normal technologies and those related to conservation agriculture technologies for developing the efficient water-management strategies for their farm-level impact in India. Key technological innovations such as precision land levelling, no-till systems, FIRB planting systems, crop diversification and its residue management have been blended for efficient water use and WUE for sustainable farming systems (Praharaj *et al.*, 2011; 2016; Mishra *et al.*, 2012a,b).

**Table 3.** Effect of drip-fertigation on yield, economics, water-use efficiency (WUE) and soil organic carbon (SOC) under long-duration pigeonpea

| Drip-fertigation (at stages) | Grain yield (kg/ha) | Net returns (Rs'000/ha) | WUE (kg/ha-cm) | Agronomic efficiency (kg grain/kg NPK) | SOC (%) | |
|---|---|---|---|---|---|---|
| | | | | | 0-15 cm | 15-30 cm |
| Rainfed | 2,858 | 66.4 | 58.2 | 10.6 | 0.27 | 0.18 |
| Drip$^{Br}$ | 3,419 | 74.9 | 66.9 | 16.9 | 0.31 | 0.23 |
| Drip$^{Pod}$ | 3,092 | 64.4 | 60.1 | 13.2 | 0.28 | 0.19 |
| Drip$^{Br+Pod}$ | 3,468 | 76.1 | 65.1 | 17.4 | 0.32 | 0.25 |
| Furrow Irrigation$^{Br+Pod}$ | 3,262 | 74.5 | 60.2 | 15.0 | 0.29 | 0.22 |
| CD (P=0.05) | 225 | 7.01 | 4.4 | 2.6 | 0.21 | 0.17 |

*Br, Branching; Pod, Pod formation; WUE, Water-use efficiency; SOC, Soil organic carbon

## DRAINAGE CONSIDERATIONS (*KHARIF*)

Constraints analysis resulting in low production in *kharif* pulses revealed that excess soil moisture or waterlogging during the monsoon season and unseasonal rainfall even during *rabi* (*fall*) season creates unfavourable conditions for crop growth. These include reduced aeration, hampered nodulation, reduced nutrient uptake, and favourable environment for blight and seedling rot resulting in reduced crop stand and poor yield (Praharaj *et al*., 2015a). Thus, the effect of suitable land configuration such as ridge and raised-bed planting has a role in maintenance of optimum plant population and crop productivity vis-à-vis flat planting/ broadcasting (Singh *et al*., 2015). On the other hand, moisture stress in the post-monsoon period adversely affects the development of reproductive organs leading to depressed yields. Thus, *soil moisture-related limitation* is the major constraint to higher productivity of pulses in Indian Subtropics.

Water-resource conservation with appropriate resource conserving technologies (RCT) involving new crop-production technologies are usually associated with reduction in tillage operations/ mechanical operations, appropriate crop or animal husbandry with suitable crop(s) or cropping/ farming systems and more biomass (crop) or residue retention on the soil surface. These play a key role in sustainability of crop-production systems. Conservation agriculture (CA) through its key components articulated with fortification (Sangar *et al*., 2004) through adequate soil cover, least soil traffic and appropriate cropping systems could prove to be a giant leap towards sufficiency in agricultural production. Not only in India but globally the water, *the most precious natural resource*, has to be conserved, recycled and channelized through cultivation of water-efficient crops or enterprises for the livelihood security of teeming millions.

## TECHNOLOGY SCALING

Application of certain viable technology such as efficient management of water through optimum water-saving measures such as micro-irrigation for rainfed areas has to be popularized at both local and global level keeping in view the consistent depletion of water resources and competing factors needing potable water. This has been more accentuated now-a-days because of recent spurt in the climate change and higher frequency of extreme climatic events. In addition, managing agro-inputs with the help of modern techniques such as micro-irrigation is crucial to enhance agricultural productivity through improved input-use efficiency (Praharaj and Kumar, 2012). Further impetus in input-use efficiency and productivity *per se* could also be increased through incorporation of suitable short-duration intercrops/ strip cropping during the rainy season including cereals, *viz*., sorghum [*Sorghum bicolor* (L.) Moench], pearlmillet [*Pennisetum glaucum* (L.) R. Br.], maize (*Zea mays* L.) and other minor millets; pulses, *viz*., mungbean and urdbean; oilseeds, viz., sesame (*Sesamum indicum* L.), soybean and groundnut; and vegetables (for leaves or fruits) depending on demand/requirements of commodities for the region. This is more important in the context of understanding agro-ecology of a region and socio-economic condition of the clientele (farmers) and applying sound agricultural principle then and there in order to achieve a stability in agricultural production (and productivity) for a better future.

Therefore, adaptive strategies for conservation agriculture systems will also be highly site specific yet learning across the sites will be a powerful way in understanding why certain technologies or practices are effective in a set of situation and not effective in another set. This will greatly accelerate our *learning process* for a sustainable resource management. Thus, precision irrigation has emerged as a way for transition to the sustainability of intensive production systems. Since precision agriculture permits improved and efficient management of water and soils for agricultural production, it has assumed importance in view of the widespread natural resource degradation. This is attainable through effective and appropriate precision strategies aided with improved technologies.

Attempts to promote precision water application globally are underway as reflected from developments worldwide where the objective of bringing together farmers, scientists, private sector stakeholders and decision-makers to share information and experiences and to encourage interaction for future research and development efforts (Praharaj *et al.*, 2014). Similarly, adoption of a particular technology say, *micro* or *drip irrigation* was influenced in most cases by scarcity of water. Serious problem associated with the system is salt encrustation and clogging of conveyance pipes in case of salt water. While ranking the reasons for non-adoption of drip irrigation by Garetts ranking technique, salt encrustation and clogging of conveyance pipes ranked first, followed by high initial cost, delay in incentives amount disbursement and finally undulated terrain nature (Palanisamy and Palanisamy, 2000). To meet the high initial cost and to popularize these water-saving method (Sharma *et al.*, 2012), the Government has extended incentives for varying categories of farmers at present up to 50% of the drip-irrigation system cost (Asokarajan and Palanisamy, 2003). It is established therefore, that the primary constraint in maintaining or enhancing pulses production in India especially in semi-arid regions (rainfed and drylands), has been shortage of water every year for 7.5 to 10 months along with the widespread nutrient deficiencies (ICAR, 2016) in soils for which good agricultural practices (GAP) or management plays a crucial role. In this context, the role of policy support to enhance overall pulses production in the country to make it self-reliant in pulses sector (Singh, 2013; ICAR, 2016) is noteworthy.

## ECOSYSTEM SERVICES

Inclusion of pulses or incorporation of pulses residue has astounding impact on soil health and, nutrient recycling for better nutrient management and over all mitigation of climate change. Besides BNF, grain legumes also supplement the soil nutrient stock and mineralize the non-labile nutrient pool by way of leaf fall, residue recycling, root exudates and below ground exudates. In the long run the beneficial impact of legumes was also increased manifolds (Ganeshamurthy, 2009). Thus, significant improvement/benefits in soils under pulses compared to non-pulses include concentration of carbon, microbial biomass, soil enzyme content, and organic and total soluble N. Pulses also do contribute to an increased diversity of soil flora and fauna lending a greater stability to the total life of the soil (Borase *et al.*, 2020a, 2020b). This indicates that the inclusion of pulses in crop rotation could enhance the soil nutrient cycling and plant acquisition, hydrolysis of organic compounds, and microbial growth. It is also observed that soil microbial biomass C (SMBC) and N (SMBN) increased by about 30 and 200%, respectively, when maize (*Zea mays* L.) was rotated with cowpea compared to monoculture maize (Yusuf *et al.*, 2009). Further, root exudates released by pulses and organic matter added to the soil enable transformation of unavailable soil nutrients to available forms. Further, legume inclusion found to curtail the emission of greenhouse gases (GHG) in the atmosphere (Lal, 2017).

***Low carbon and water footprint:*** Carbon footprint can be defined as 'a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product' (Gan *et al.*, 2011). This is mainly emphasized on $CO_2$ emission. However, many other greenhouse gases (GHGs) like, $N_2O$ (300 times more global warming potential than $CO_2$) are also released under different farming activities. The GHGs emission under cereal-cereal cropping systems in general is decreased following inclusion of oilseeds and pulses, and more so under pulses. Durum wheat preceded by pulses (chickpea, lentil & pea) lowers its carbon footprint up to 34.2% (Table 4). This showed that diversification of cereal-cereal system with pulses lowered the carbon footprint of cereal crops (Hazra *et al.*, 2019).

**Table 4.** Carbon footprint of diversified cropping systems (Gan *et al.*, 2011)

| **Cropping system** | **$CO_2$e kg/ kg grain yield** | **Reduction (%)** |
|---|---|---|
| Cereal-cereal-durum wheat | 0.420 | 0 |
| Cereal-oilseed-durum wheat | 0.379 | 9.8 |
| Cereal–pulse–durum | 0.333 | 20.6 |
| Pulse–cereal–durum | 0.331 | 21.1 |
| Pulse–oilseed–durum | 0.326 | 22.4 |
| Pulse–pulse–durum | 0.276 | 34.2 |

$CO_2$e: $CO_2$ equivalent

Similarly, on low water footprints, pulses are the key contributors. Ground water depletion is major concern in IGP due to continuous growing of rice-wheat cropping system (Nath *et al*., 2019). The problem is more serious in Trans- and Upper-IGP regions. Pulses in general require lower amount of water and hence, can be used as an alternative to cereal crops in this region (Praharaj *et al*., 2016, 2017). However, higher grain yield based water footprint (WF) was reported (an average of 1.59 $m^3$/kg for pulse crops and 1.18 $m^3$/kg for cereal crops) but a lower (Ding *et al*., 2018) protein yield-based WF (an average of 6.58 $m^3$/kg for pulse crops and 9.25 $m^3$/kg for cereal crops) than cereal crops (Table 5). Further, under rainfed condition, higher water footprint of pulses (pigeonpea, urdbean and cowpea) was reported than cereal crops, like maize (Kar *et al*., 2014).

**Table 5.** Water footprint of different crops (Ding *et al*., 2018)

| Crop | Grain yield based WF ($m^3$/kg) | Protein yield based WF ($m^3$/kg) |
|---|---|---|
| Spring wheat | 1.08-180 | 7.69-10.44 |
| Barley | 0.90-138 | 8.27-16.47 |
| Canola | 1.71-2.58 | 3.79-7.55 |
| Sunflower | 1.94-4.28 | 4.86-11.17 |
| Lentil | 1.47-2.37 | 5.09-7.42 |
| Chickpea | 1.39-1.79 | 5.51-10.69 |

On income /employment generation front, pulses can play an important role in improving monetary output and securing employment generations for the farming community. Pulses serve multipurpose role by not only supplementing dietary needs but also restoring soil health and thereby upgrading the overall system productivity. Pulses can also play as an excellent option for doubling farmer's income by 2022 as prospected by Government of India as experimental evidences across India showed the benefits of pulse inclusion resulting in scaling in farmers' income. According to Ministry of Agriculture and Farmers Welfare, Govt. of India, 2018-19, inclusion of pulses in cropping systems can increase monetary return up to 75% (Table 6). Besides this, energy saving through nitrogen economy by different legumes is substantial (Table 7). Similarly, the ground water pollution due to leaching of nitrates is major concern in rice-wheat growing regions of IGPs. The inclusion of pulses as intercrop with cereals reduces nitrate leaching. For example, it was observed that sugarcane+ urdbean and pigeonpea + maize intercropping resulted in low nitrate nitrogen leaching compared to sole cropping (Yadav, 1982).

**Table 6.** Monetary benefits of pulse inclusion in cropping systems (MoA&FW, GoI, 2018-19)

| Crop | Absolute increase | Percentage increase | Return over cost (%) |
|---|---|---|---|
| Pigeonpea | 225 | 4.13 | 65.4 |
| Mungbean | 1400 | 25.11 | 50.0 |
| Urdbean | 200 | 3.70 | 62.9 |
| Chickpea | 200 | 5.00 | 75.2 |
| Lentil | 225 | 5.13 | 76.7 |

**Table 7.** Energy saving through nitrogen economy by different legume based systems (Ahlawat *et al*.,1981; Ahlawat, 1998)

| Preceding Legumes | Succeeding cereal | N economy (kg/ha) | Energy saving ($10^8$ joules/ha) |
|---|---|---|---|
| Chickpea | Maize | 56-68 | 45-54 |
| Chickpea | Pearlmillet | 40.0 | 32.0 |
| Lentil | Maize | 18-30 | 14-24 |
| Lentil | Pearlmillet | 40.0 | 32.0 |
| Peas | Maize | 20-32 | 16-25 |
| Peas | Pearlmillet | 40.0 | 32.0 |
| Lathyrus | Maize | 36-48 | 29-38 |

## CONCLUSION

From the foregoing discussion, it is proved that the primary constraint in maintaining or increasing pulses production in the arid/semi-arid/semi-arid regions has been shortage (and, on a few occasions surplus) of water. Thus, Good Agricultural Practices (GAP) involving appropriate water conservation and its management plays the most important role. Within the technology framework, substantial productivity enhancement in pulses could be possible with short-duration varieties that fit well in different (inter-) cropping systems so as to augment vertical expansion of pulses in the country. Therefore, improved agro-technologies in relation to water use have been a boon to profitable pulses cultivation. There is also a need for synergy for holistic water management not only water *per se*. Introduction and popularization of grain legumes as a water-efficient enterprise could emerge as a transition towards sustainability in intensive agricultural production systems in India against a possible natural resource degradation/ vagary of climate. Therefore, the importance of pulses in ecosystem services is multidirectional and mammoth.

## WAY FORWARD

With a massive '*Grow More Pulses Campaign*' for motivating and providing further incentives for farmers, there is a need to address certain areas in a time-bound manner for immediate redressal of water issues in agriculture. Modern techs such as improved land configuration, supplementary irrigation through efficient irrigation methods like sprinkler and drip, adoption of intercropping/ mixed cropping and improved crop husbandry are avenues for boosting production in pulses. For example, inclusion of chickpea, lentil, lathyrus and urdbean in rice fallows, and that of mungbean and pigeonpea in rice–wheat cropping system and pigeonpea at high altitudes will help in diversifying existing system and reducing pressure on agro-ecosystems. Even there is a need to include pulses in traditional rice-wheat system. Using high-yielding varieties of pulses and adopting efficient crop production technologies will certainly help in this regard. Dissemination of proven technology along with provision for making availability of quality critical inputs on time at affordable prices to farmers will have the desired goals. Similarly, adequate financial and other resources must be committed for research and development efforts exclusively for pulses in proportion to currently provided to cereals and cash crops. In this endeavour, improved varieties with drought tolerance provide a fillip for long-term solution against adverse effects of recurrent droughts being witnessed in one or the other part of the country every year. Similarly, research needs to be intensified to develop high-yielding, short-duration strains which escape terminal drought, as it could facilitate farmers to include them in a given cropping systems. Besides these, Public–Private–Partnership (PPP) mode can facilitate to increase the availability of breeder and foundation (and, quality seeds with Seed hubs) seeds meet the current and emerging needs of seed-producer companies and as a fillip to national and states seed productions.

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