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REVIEW PAPER

Improved production technologies for harnessing genetic potential in semi arid tropics of India

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Abstract: Demand for food and other agri-products continues to accelerate and to meet this galloping need under of deteriorating production environment and challenging climate change, while breeders and biotechnologists are busy in pushing the genetic potential, agronomists and growers are trying to reach the ever elusive potential thresholds through better production practices. Presently, the yield gap between the actual and the potential for many crops being in the range of 15 to 60 %, the prime task before production scientists is to bridge this gap. Innovative practices such as transplanting, drilling (rice), nipping, raised seed bed, zero till *etc*. are helpful in improving source and sink potential while technologies such as drip irrigation, fertigation, seed priming, resource optimization, yield targeting *etc.* being strategic aim for bettering resource use efficiency and yield maximization. Experimental evidences in semi arid tropics of India suggest betterment in yield by 10-15 % with some practices to as high as 50-70 % with critical interventions, and in yield targeting the realization at higher targets most of the time was 92-97 %, while in some cases it par excelled. A few of such promising practices and technologies enabling realization of crop potentialare briefed in this paper.

Key words: Fertigation, Fortification, Innovative practices, Strategic technologies, Yield targets

Introduction

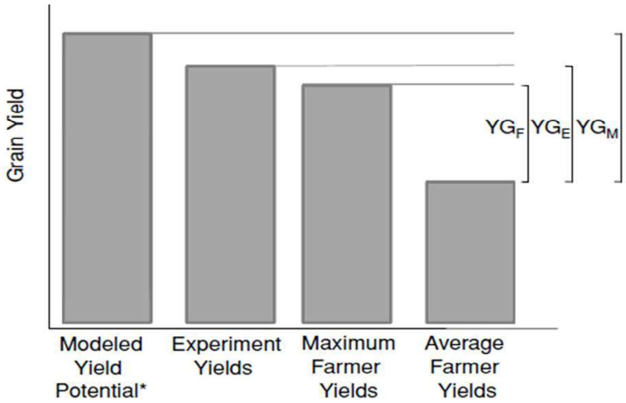
Agriculture is a key activity of human being for stable livelihood since civilization as it provides basic needs such as food, clothing and shelter besides profits for trade. Food security, however, is being challenged due to declining profit, deteriorating production environment and changing climatic conditions. It is projected that there would be 60% increase in demand for agricultural production by 2050 (Anon, 2012), which is very large yet attainable. And, this has to happen with decreasing land under plough, depleting natural resources and changing climate. No doubt, modern agricultural science and molecular biology technologies have boosted the production of several crops over the past few decades through the development of new and more productive germplasm, but there have been evidences of partial realization of genetic potential on farms in general, while there have been yield plateaus or decreasing yield gain rates in some crops at places in recent years. Efforts in harnessing near full genetic potential or closing the 'yield gap' are much warranted to improve not only the productivity but also the efficiency of production wherein agronomy plays a crucial role.

In India, for instance, yield gap in rice varied from 15.50 to 60% with the national average gap of 52.30% in the irrigated ecosystem (Siddiq, 2000), and 2560 kg ha^{-1} for rainfed rice (Aggarwal *et al.*, 2008). Nirmala *et al.* (2009) estimated 12.46% yield gap in rice in Raichur district of Karnataka, between potential yield realized at research station and the yield from the demonstration plot. National average yield gap compared to China and other east Asian nations is substantial (Table 1), and the story is true for many other important crops (Aggarwal *et al*., 2008, Lobell *et al*., 2009, Pushpa and Srivastava, 2014, Mondal *et al*., 2018 and Rathore *et al*., 2018).Further, there also exists wide yield difference among cultivars used, soils under cultivation, cultural practices followed *viz*, time of sowing, soil and foliar nutrition, farmers technical and investment potential *etc*. in a region as observed in case of cotton by Hosamani (2017) in Tunga Bhadra Project (PBP) and Upper Krishna Project (UKP) irrigation commands of Karnataka. Closing yield gaps to attain potential yields may be a viable option to increase production and sustain food security. Since traditional methods of agricultural intensification often have negative externalities, there is a need to explore location-specific methods of sustainable agricultural intensification (Pradhan *et al*., 2015). They opined that by closing yield gaps in the current irrigated and rainfed cultivated land, about 24% and 80% more crop calories can respectively be produced compared to year 2000.

The term 'yield gap' has been commonly used to refer to the difference between the average farmers' yields and an estimate of a reference yield or potential yield at a specific area in a given time (Fig. 1, Lobell *et al*., 2009). Yield gaps exist because the best available production technologies are not adopted in farmers' fields which could be due to farmers'

Table 1. Yield levels and yield gaps in rice of major countries of Asia region

Country	National average yield (t ha^{-1})	Irrigated/ better managed yield (t ha^{-1})	Yield gap (t ha^{-1})	Yield gap %
India	2.60	3.60	1.00	27.78
Nepal	2.50	4.20	1.70	40.47
Thailand	2.00	4.00	2.00	50.00
Vietnam	3.10	4.30	1.20	27.90
Indonesia	4.40	5.30	0.90	17.00
Philippines	2.80	3.40	0.60	17.65
China	5.70	5.90	0.20	3.38



YG_M - Model-based yield gap, YG_E - Experiment-based yield gap and YG_F - Farmer-based yield gap

Fig 1. A conceptual framework depicting the relative rankings of average farmer yields and three measures of yield potential

personal characteristics, farm characteristics, and unsuitability of the technology to farmers' circumstances. Nevertheless, the concerted efforts of agronomists including proactive growers are raising hopes in the Semi arid tropics of India. A few of the precision and proficient technologies that enable maximizing crop potential particularly of small and medium holders are deliberated in this paper.

A. Innovative Practices

1. Planting methods and regulating the plant canopy

a. Transplanting in arable crops

Pigeonpea is a leading pulse almost assuming the commercial status, of late its productivity is vulnerable due to *Helicoverpa* pod borer and changing climate and rarely potential yields (3.75 – 4.5 t ha^{-1}) are realized. Crop being photesensitive proper time of planting is critical; planting early in the season with the onset of monsoon is more paying as it ensures adequate soil moisture throughout life cycle, and accumulate required growing degree days (GDD) besides escaping from pod borer. Recently transplanting technique [Notheastern transition zone (Chittapur, 2016) and Northeastern dry zone (Pavan *et al.*, 2011), and Eastern Gangetic plains of India (Praharaj *et al.*, 2015)] is emerging as one of the alternative/smart agronomic practices to overcome yield reduction associated with late sowing (Table 2). Transplanting of 25-30 days old poly bag (of 5-6" dia/height, transplant keeping roots undisturbed with ball of earth) raised seedlings produced more yields than conventional dibbling as the established seedlings pick up their growth from where they have stopped in the nursery and become competitive, besides help to reap the benefits of early sowing (Potdar, 2016). Further, wider planting facilitates spray of insecticides and air movement within the plant canopy. It is a tailor made technology for small and marginal farmers.

Table 2. Yield and economics of transplanted pigeonpea as influenced by planting geometry

Spacing (cm x cm)	Plant population (no. ha^{-1})	Yield (kg ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
90 x 90 (Trans.)	12345	1306	30357	3.43
120 x 90 (Trans.)	9250	1624	43197	5.16
150 x 90 (Trans.)	7405	1443	38516	5.23
90 x 20 (Recd.)	5555	986	22288	3.17
C.D. 0.05		167		

Trans.-Transplanted, Recd.-Recommended seed dibbling

Late planting is also a problem in Bt cotton in the irrigation commands of northern and north eastern dry zones of Karnataka. Rajkumar and Gurumurthy (2008) revealed the scope for transplanting in cotton similar to pigeonpea. Subsequent studies in TBP and UKP irrigation commands confirmed higher seed cotton yield (32%) with transplanting of cotton at 90 x 90 cm spacing over farmers' practice of dibbling of seeds, due to increased sympodials, bolls and seed cotton yield per plant (Table 3). The cost of planting was covered by the increased income (39%) realized through the technique (Salakinkoppa *et al.*, 2010, Honnali and Chittapur, 2013 and Pyati *et al.*, 2017). Importantly, transplanting ensured efficient use of water and growing season and was superior to paddy-paddy system banned in the UKP irrigation command. At MARS, Raichur, transplanting of seedlings out yielded (3457 kg ha^{-1}) seed dibbling (3280 kg ha^{-1}) and the difference widened with delay in planting (50 kg to 266 kg ha^{-1}) (Pyati *et al.*, 2017). Among all, June 1st fortnight transplanted crop produced significantly higher seed cotton yield (4426 kg ha^{-1}) followed by dibbled crop during the same period (4376 kg ha^{-1}) owing to better growth. Yield decreased by 967 kg to 1042 kg ha^{-1} with July 1st fortnight over June 2nd fortnight planting with dibbling and transplanting, respectively. August 1st fortnight planted crop recorded the lowest yields (1640 and 1906 kg ha^{-1}with dibbling and transplanting, respectively) among all. They, however, opined that time of planting appeared more critical than the method of planting in cotton.

b. Drill sown rice (DSR) in irrigation commands

With the joint efforts of CIMMYT and University of Agricultural Sciences Raichur, Karnataka, development and validation of DSR technology had shown promise for its out-scaling through innovative strategies in the areas where water supplies are limited and farmers do not get sufficient water at right time particularly initially and are constrained with ON-OFF canal water supply (Chittapur, 2016). Response to early

Table 3. Yield and economics of cotton as influenced by transplanting

Spacing (cm x cm)	Seed cotton yield (t ha^{-1})				Net returns (₹ ha^{-1})	B:C ratio	% leaf reddening
	On research farm	% increase	On farmers' field	% increase			
90 x 90	1.84	32.4	2.09	20.2	48610	2.33	6.35-7.20
90 x 60	1.72	23.5	2.07	19.5	40110	2.12	8.60-9.55
90 x 45	1.39		1.74		34700	2.12	17.7-20.50

dry seeding to take advantage of early rains received before canal supplies was met with imminent success with farmers (Table 4) (Ramesha and Basavanneppa, Personal Communication). In addition to increase in net income, timely sowing, reduced seed rate by half, reduced fuel consumption by 40-50 l ha^{-1}, reduced water use by 25-35%, reduced emission of GHGs, and increased nitrogen use efficiency are the other benefits (Rajesh, *et al*., 2016, Shubha, 2017 and Jagadish, 2018). In fact, among establishment methods tested, SRI method was comparable to transplanting but with lesser water applied and higher water use efficiency and mitigation of GHGs (13.92%) (Jagadish, 2018) (Table 5).

c. Nipping

Nipping, the removal of terminal bud/s, is common practice in crops like cotton, castor, field peas, chickpea, safflower, chrysanthemum *etc.* to arrest the apical dominance and encourage fruit bearing auxiliary branches. Similarly, nipping is a novel practice in pigeonpea. In northern Karnataka, nipping of 5-6 cm main shoot tip growth in pigeonpea at 20-25 days after transplanting or between 50 and 55 days of germination and pruning of the secondary branch tips is recommended to promote development of large number of tertiary shoots which bear more number of pods, thus increasing the yield by 30-50% (Sharma *et al*., 2003).Similarly at Regional Agricultural Research Station, Warangal, Telangana on Vertisols, single time nipping at 45 days after sowing (DAS) was superior to nipping twice at 45 and 60 DAS or single nipping at 60 DAS and across different plant stand it recorded significantly higher seed yield (1688 kg ha^{-1}) over no nipping (1412 kg ha^{-1}), The yields with 41,666 plants ha^{-1} (1763 kg ha^{-1}) and 27,777 plants ha^{-1} (1748 kg ha^{-1}) along with single nipping were comparable, while population alone did not affect the plant performance (Veeranna *et al*., 2020) (Table 6). Now, the technology is spreading among farmers and mechanical nipping is making the task easy.

Table 4. Yield (kg ha^{-1}) of drill sown rice genotypes under varied dates of sowing and large scale demonstration in TBP area

Genotypes	2nd FN	1st FN	2nd FN	1st FN	2nd FN	Mean	Largescale demonstration	
June	July	July	Aug	Aug		Average	Maximum	
GGV-05-01	6057	5966	5798	5607	4456	5577	-	
RNR-15048	5741	5701	5597	5401	4187	5326	8061	8950
BPT-5204	5443	5129	4989	4712	3797	4814	8383	9220
GNV-10-89	5966	5904	5732	5465	4189	5451	7250	7250
Mean	5802	5675	5529	5296	4157			
CD (0.05)	Dates - 282		Varieties - 262		Interaction - NS			

FN - Fortnight

Table 5. Performance of paddy as influenced by establishment methods and irrigation scheduling

Treatment	Yield (kg ha^{-1})	N uptake (kg ha^{-1})	NUE (kg kg^{-1})	Net returns (₹ ha^{-1})	Total water used (mm)	WUE (kg ha mm^{-1})
Establishment method (M)						
M_1	4431^{b}	85.2^{d}	71.4^{b}	35589^{b}	733.7^{d}	7.69^{a}
M_2	4599^{b}	91.1^{c}	73.6^{b}	38093^{b}	800.6^{c}	7.14^{ab}
M_3	4875^{a}	107.2^{b}	78.9^{ab}	42324^{a}	882.2^{b}	6.78^{b}
M_4	5060^{a}	130.3^{a}	83.7^{ab}	45105^{a}	1044.3^{a}	5.76^{c}
S.Em.±	58	0.8	2.6	988	15.0	0.15
Irrigation schedule (F)						
S_1	4678^{b}	96.6^{c}	76.1^{ab}	39386^{b}	865.2	6.69^{ab}
S_2	4914^{ab}	111.5^{b}	78.4^{ab}	43157^{ab}	865.2	7.04^{a}
S_3	5049^{a}	122.7^{a}	80.5^{a}	45231^{a}	865.2	7.22^{a}
S_4	4324^{c}	83.0^{d}	72.4^{b}	33336^{c}	865.2	6.42^{b}
S.Em.±	90	1.8	2.5	1478		0.14

M_1- Dry-direct seeded rice (Dry-DSR), M_2- Wet-direct seeded rice (Wet-DSR), M_3- System of rice intensification (SRI)
M_4- Transplanted paddy(TPR).
S_1- Alternating wetting and drying (AWD), S_2- Critical stage irrigation at germination,tillering,flowering,panicleiniationand grain development
S_3- Saturation and S_4-Farmers' practice
NUE - Nitrogen use efficiency, WUE - Water use efficiency
Means followed by the same letter(s) within a column do not differ significantly by DMRT (p=0.005)

Table 6. Effect of nipping on the performance of pigeonpea in Karnataka and Telangana

Location	Nipping	Seed yield (kg ha^{-1})		Source
Kalaburagi,Karnataka	No-nipping	1287	S.Em.±40	Sharma *et al*. (2003)
	Nipping at 50 DAS	1466 (13.9)*		
	Nipping at 50 and 70 DAS	1158	CD(0.05)112	
	Nipping at 50, 70 and 90 DAS	1062		
Warangal,Telangana	No-nipping	1386	S.Em.±40	Veeranna *et al*. (2020)
	Nipping at 45 DAS	1688(21.8)		
	Nipping at 60DAS	1412	CD(0.05)116	
	Nipping at 45 and 60 DAS	1493		

* % increase over no nipping DAS – Days after sowing

2. Better seed bed for improving crop productivity and soil health

Appropriate land configuration and soil management of seed bed aims to maintain and improve the soil productivity by improving the availability and plant uptake of water and nutrients through enhanced soil biological activity, replenishing soil organic matter and soil moisture, and minimizing losses of nutrients (Choudhary *et al.,*2015, Choudhary *et al.,* 2018 and Varatharajan *et al*., 2019a and b). Soil water and temperature are interrelated due to changes in thermal conductivity and heat capacity with water content and also movement of water due to thermal gradients. Chiroma *et al.* (2006) reported that land configuration practices coupled with mulching improved the soil porosity, SBD and soil strength. Varatharajan *et al.* (2019a, b) observed beneficial effects of land configuration on yield and quality of pigeonpea. Overall, land configuration has great bearing on plant growth, productivity and soil quality.

a. Sand mulching

In spite of high moisture holding capacity, utilization of black soils particularly the *kurl* soils for crop production is limited to a few crops because of poor aeration and ill drainage due to high clay content (>60%) and exchangeable sodium. In such soils sand mulching has been practiced by farmers in some pockets (Gadag-Koppal) of North Karnataka and such a system found to help farmers to harvest two crops namely greengram/groundnut-*rabi* sorghum/safflower in a growing season. The system does not warrant yearly ploughing. Soil cracking during summer is either minimal or not visible. Experiments conducted at Dry farming centre, Bijapur and Main Research Station, Dharwad, indicated advantage with sand mulching (Guled, 1999, Sudha, 1999 and Surakod, 2015). It is observed that the soil moisture under sand mulch could be 85 to 95% compared to unmulched soil because of increased rain water retention and reduced evaporation. Approximately 100 - 120 tractor loads of sand per ha is used. The increase in grain yield of greengram was from 2.5 to 10 q ha^{-1}, sunflower 3 to 12.5 q ha^{-1}, and *rabi* sorghum 2 to 10 q ha^{-1}. The amount spent on sand mulching could be recovered within a year, besides the cropping intensity could be increased by 200%. Benefits with sand mulch exceeded those due to compartmental bunding and tied ridges at Regional Research Station, Bijapur (Surakod, 2015). Similarly, a uniform layer of pebbles on the soil surface reduces the evaporation loss. It also helps to control runoff. No gullies could be seen in the pebble mulched fields. The soil moisture will be maintained for longer period and that is why yields are always higher in areas naturally covered with pebbles on the surface. Pebble mulches particularly on slopes can also reduce soil erosion during rainfall event and hence make cropping possible. Double cropping is also possible in pebble mulched areas.

Guled (1999) attributed the beneficial effects to runoff control and increased wetting time. Haung (1983) attributed improved crop performance to increased soil temperature, conservation of rain water, reduced evaporation, and wind and water erosion which in turn increased water content all the time under sand mulch compared to unmulched soil. The benefits are directly proportional to the quantity of sand applied and mulch layer thickness. Unger (1971) found that the surface sand mulch was more effective than a sub surface layer in preventing evaporation and leaching, whereas a gradual decline in the yield was observed with increase in thickness of sand mulch up to 30 cm. Similar observations were made by Sudha (1999) who revealed that 10 cm thick sand layer produced lower groundnut pod yield compared to 5cm thick sand mulch. They concluded that sand application of 5 – 7.5 cm thickness was beneficial. However, limitation of availability, huge requirement, restriction on sand removal from nala beds of late and transportation costs work against this measure wherein localized application needs consideration.

b. Set furrow cultivation

Rain water management practices are tailored to store and conserve as much of rainfall as possible in the place where it falls by reducing runoff and increasing storage capacity of the soil profile. The most efficient and cheapest way of conserving rainfall is to hold it *in situ.* The water stored in the soil is readily available to the plants and substantially increases the crop yield with normally available rain water. The experiment at Regional Research Station, Bijapur revealed that application of tank silt in set furrows (45-90-45 or 45-135-45 cm, and wide rows at 135 cm) significantly increased soil moisture content at sowing and at all the growth stages (Table 7) (Yadahalli *et al*., 2014a and b). At sowing, application of tank silt + crop residue in set furrows (135 cm) recorded significantly higher volume of water (28.58 cm) than farmers' practice (16.39 cm) in top 100 cm soil depth and reduced the water deficit in the crop root zone and runoff (3.86 and 26.39 mm, respectively). The practice resulted in 77.24% higher pearlmillet yield (1737 kg ha^{-1}) over farmers' practice (980 kg ha^{-1}) and was on par with tank silt + crop residue application in set furrows with wider row spacing (135 cm) and paired row spacing (45-90-135 cm). Besides, sunflower - the second crop in succession - during *rabi* in 135 cm wide set furrows also recorded higher yield (717 kg ha^{-1}) over farmers' practice (312 kg ha^{-1}). Thus, the system enabled double cropping in shallow to medium soils where single cropping is traditional practice. Sand application in the furrows, however, was not advantageous.

c. Ridges and furrows

Warming of the soil is delayed under very wet conditions because more energy is used for evaporation and less for heating the soil and air. Ridges speed up the drying process because of gravitational effects on the water and the increased solar flux. Stone *et al*. (1989) observed that before planting, ridge-tillage resulted in higher temperature within the seed zone than the flat-plots. This increase was because of ~10% greater surface area of raised-beds (RB) than the flat-beds (FB) absorbing more solar radiations. Grewal and Abrol (1990) found more soil water content in ridge system as against the flat-planting. Pathak *et al*. (1991) found significantly lower soil bulk density of 0–15 cm soil layer in RB than the FB system in chickpea. Furrows are more advantageous as they increase

Table 7. Pearlmillet equivalent yield (PEY) of pearlmillet – sunflower sequence cropping system as influenced by tank silt application and row spacing under set row cultivation (Pooled data of 3 years)

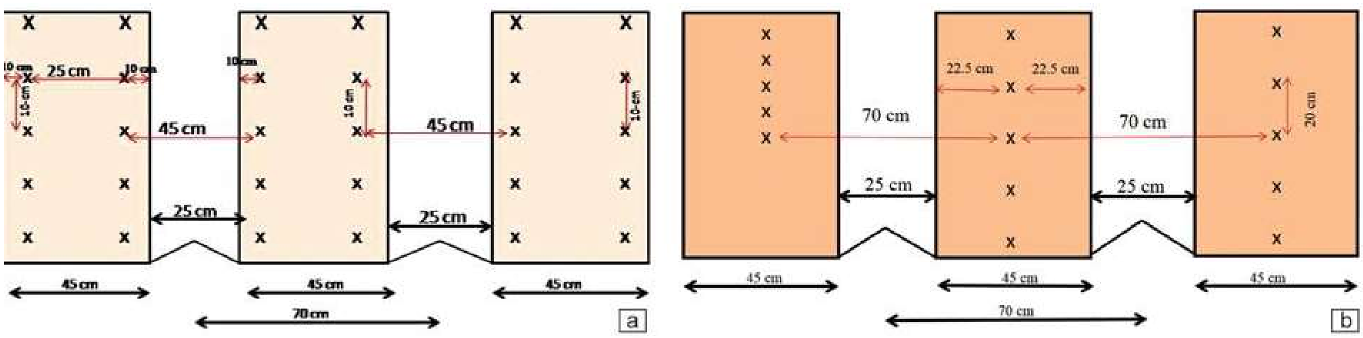
Treatment	PEY (kg/ha)			Soil moisture content (cm/m)							
				Pearlmillet				Sunflower			
	Pearlmillet	Sunflower	Total	At sowing	30 DAS	60 DAS	At harvest	At sowing	30 DAS	60 DAS	At harvest
Farmers' practice (35 cm)	980	1015	1995	18.39	24.25	23.03	23.56	23.97	26.02	21.01	10.45
Recommended Practice (60 cm)	1196	1436	2631	19.52	26.71	26.08	25.90	25.72	28.40	23.64	12.25
Silt in set furrows (135 cm)	1700	2435	4135	28.53	34.05	33.00	32.60	32.10	35.45	29.40	18.05
Silt in set furrows (45–90–45 cm)	1716	2284	4000	26.78	33.17	31.79	32.04	31.07	33.37	28.81	16.07
Silt in set furrows (45-135-45 cm)	1737	2353	4090	27.76	33.11	32.50	32.77	30.42	34.36	28.80	16.60
Flat bed (135 cm)	1417	1863	3281	21.74	29.35	28.79	28.86	27.85	30.30	25.90	14.24
Flat bed (45 – 90 – 45 cm)	1431	1719	3151	22.53	27.85	27.81	27.10	27.09	28.62	24.75	13.29
Flat bed (45 – 135 – 45 cm)	1443	1768	3211	22.64	28.80	28.69	28.80	27.64	29.86	25.25	12.62
S. Em ±	43	60	92	0.95	0.77	0.34	1.00	0.87	0.84	0.72	0.58
C.D at 5%	129	218	280	2.88	2.34	1.03	3.03	2.63	2.56	2.18	1.77

DAS – Days after sowing

moisture recharge in the soil by collecting water and simultaneously help in draining away excess water. For instance, groundnut is generally sown on flat beds using a seed drill but hand dibbling of seeds on either side of the ridge prevents the plants coming in direct contact with the standing water under excess rains besides helping early aeration of rhizosphere which is very important in groundnut (director.dgr@icar.gov.in, Wani *et al*., 2005). While in pigeonpea in northern dry zone of Karnataka with lower rainfall, ridges and furrow system of land configuration and seed dibbling on/side of ridges resulted in higher yields in demonstration under NICRA project due to conservation of moisture in the furrows. The furrows are especially useful under changing climatic scenario with unprecedented rains in draining of excess water; otherwise the standing water would kill the sensitive pigeonpea plants.

d. Raised seed bed

Choudhary *et al.* (2018) and Varatharajan *et al.* (2019a and b) suggested some planting geometries/ land configurations as well as tillage systems for higher productivity and resource-use efficiency in soybean and pigeonpea crops (Fig. 2). On the raised-beds (bed/furrow width of 45 cm) soybean should be planted in two rows with a row distance of 25 cm while leaving 10 cm space on the edges of each plain platform besides maintaining 10 cm plant to plant distance (Fig 2a). While, for medium to tall statured pigeonpea varieties, raised raised-bed (RB)/P(pemanent)RB with bed width of 70 cm should be maintained where pigeonpea seeds are sown in the centre of each bed in single row having row to row distance of 70 cm and plant to plant distance of 20 cm (Fig 2b). Varatharajan *et al.* (2018, and 2019a) reported that by adoption of land configurations and tillage systems, the pigeonpea yield was considerably higher in raised-beds under conservation agriculture (1.92 t ha^{-1}) while falt-beds under conventional tillage (CT) produced least grain yield (1.71 t ha^{-1}). CA based raised-bed sowing performed well over CT based flat-beds as well as raised-beds in terms of productivity due to better growth and yield owing to less trafficking (Paul *et al.* 2011) and better nutrient dynamics (Varatharajan *et al.,* 2019a &b) and biological properties over CT plots (Babu *et al.* 2014, Choudhary and Rahi, 2018 and Honnali *et al*., 2018), less weed stress (Das *et al.* 2017) and better moisture conservation in stress



a. Soybean b. Pigeonpea

Fig 2. Raised-bed land configuration and planting geometry for (a) soybean and (b) pigeonpea periods *vis-a-vis* less water stagnation in rainy span. Broad bed and furrow (BBF) method was useful in groundnut in areas having deep Vertisol with high rainfall (Fig 3) (Wani *et al*., 2005). This system consists of raised beds of 1.2 m width and 15 cm height with two furrows of 30 cm width on either side. Each raised bed would accommodate four rows with 30 cm spacing between rows. On an average, 15% higher yield of groundnut has been reported from the medium black soil over the flat bed. Further, Lumpkin and Sayre (2009) reported that furrow irrigation with raised-bed system saved the irrigation water by ~16-18% for a wide spectrum of legumes compared to traditional farmers' practice (Table 8).

e. Wider spacing with repeated intercultivation

Under rainfed conditions of Northern dry zone of Karnataka, wider row spacing of 120 cm with more scope for repeated intercultivation leading to soil moisture conservation, yields on par with recommended 60 cm row spacing in bajra and sunflower crops (Anon, 2020). The impact of technology is more pronounced under adverse rainfall situations.

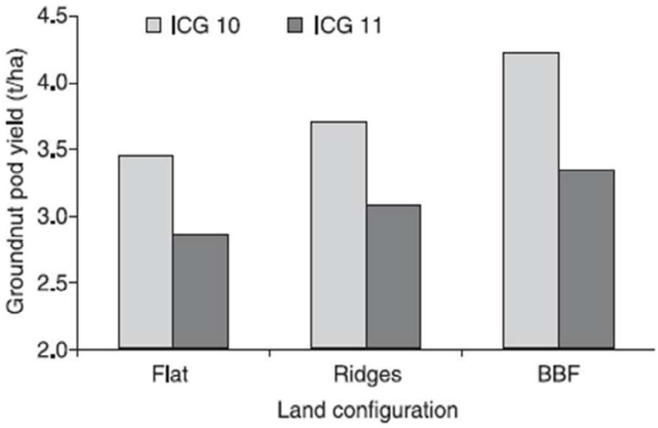


Fig 3. Groundnut pod yield, as influenced by different land surface configuration on an Alfisol

B. Strategic Technologies

1. Scaling up through nutrition

a. Seed priming

Apart from providing better soil environment, making the seed ready for stress environments is one agronomic practice particularly important for cropping under receding soil moisture, in that seed priming assumes significance as it plays important role in rapid germination, emergence, stand establishment and early vigour required for attaining required plant architecture and sink. Seed priming with nitrate salts found to help manipulate the yield-determining parameters successfully in many diverse environments (Sharma *et al*., 2009) and crops such as maize, wheat and canola (Basra *et al*., 2005). In *rabi* sorghum seed priming with KNO_3 (0.5%) resulted in significantly higher grain yield (3.03 tha^{-1}) which was higher by 16.4, 9.0 and 4.5% over the control, seed priming with water and seed priming with $CaCl_2$ (2%)- the recommended practice (Table 9) (Kubsad and Mansur, 2020). Similarly, Priya *et al*. (2011) obtained higher net returns and benefit: cost ratio with KNO_3 (0.5%) in maize and sorghum with seed priming.

b. Pulse magic

Foliar nutrition is picking up among farmers and several materials including sea weed extract are available on the shelf for the purpose. Foliar application is credited with the advantage of quick and efficient utilization of nutrients by eliminating time needed for transportation from roots, and the losses through leaching and fixation, and helps regulating the uptake of nutrients by plants (Manonmani and Srimathi 2009 and Rahman *et al.* 2014). In this practice, spray application at appropriate stages of growth is critical for proper utilization (Anandhakrishnaveni *et al.,*2004). At Zonal Research Station, Kalaburagi, to boost the productivity of pigeonpea, a combination (containing 10% N, 40% P, 3% micro nutrients and 20 ppm PGR - 10 g of nutrient mixture and 0.5 ml of plant growth

Table 8. Relative irrigation water use under different crop and land management systems

Crop	Irrigation water-use (cm)		% water saving by furrow irrigation
	Raised-bed seeding with furrow irrigation	Conventional seeding with flood irrigation	
Pigeonpea	13	15	16
Soybean	17	20	16
Greengram	17	21	16
Vegetable pea	8	10	18

Table 9. Yield and yield components of winter sorghum as influenced by seed-priming

Treatment	Germination (%)	Yield (t/ha)		Harvest index (%)	Net returns ($\times 10^3$ ha^{-1})	B:C ratio
		Grain	Fodder			
Control	66.3	2.53	5.04	31.5	37.0	2.20
Seed priming - water	73.1	2.76	5.54	30.8	38.4	2.21
Seed priming - $ZnSO_4$ (0.5%)	90.3	2.87	5.38	31.2	39.1	2.18
Seed priming - KNO_3 (0.5%)	91.2	3.03	5.62	31.7	45.1	2.43
Seed priming - KH_2PO_4 (0.5%)	88.8	2.68	5.90	29.0	37.4	2.17
Seed priming with $CaCl_2$ (2%)	90.1	2.89	5.82	29.9	42.2	2.33
S.Em.±	0.4	0.05	0.14	0.4	1.0	0.03
C.D. (P=0.05)	1.2	0.14	0.42	1.3	3.2	0.09

regulator (PGR) mixed in one liter of water) 'Pulse magic' was developed. Results of front line demonstrations under National Food Security Mission (NFSM) to reduce flower and fruit drop using pulse magic sprays twice during 50% flowering and 15 days later revealed increment in seed yield to the extent of 20% (Table 10) (Patil *et al.,* 2021). This success subsequently led to its use (single spray) in greengram and blackgram (Table 10) (Thakur, *et al*., 2017 and Patil *et al*., 2018a and b) besides, development of new combination 'chickpea special' for imparting drought tolerance to chickpea. Interestingly, farmers reported usefulness of 'Chickpea special' in *rabi* sorghum too.

c. Nutrition for targeted yields

A genotype, however, superior it may be, cannot achieve its potential unless it is put in to an enabling environment including soil in agronomic context. Soil testing and fertility management is of great importance to any country for sustained crop production. Blanket recommendation of fertilizers followed hither to has many limitations and, therefore, the new concept of target yield based nutrition particularly, in nutrition responsive and commercial crops is finding acceptance as these approaches are founded on soil fertility class (low, medium and high), nutrient contentand crop requirement. In rice nutrition, the STCR (Soil test crop response) and SSNM (site specific nutrient management based on Nutrient Expert) approaches were evaluated in TBP irrigation command area. Significantly higher rice kernel yield (7462 and 7137 kg ha^{-1}, respectively) was recorded in STCR/Nutrient expert based nutrient management with a yield target of 8 t ha^{-1} alongwith application of micronutrients (Table 11) (Shubha *et al*., 2018). In fact, 6 t ha^{-1} target was achieved without organics and micronutrients, 7 t ha^{-1} target was achieved with FYM+$FeSO_4$+$ZnSO_4$, while 8 t ha^{-1} target was less by 548 -697 kg ha^{-1} in spite of addition of organics and micronutrients which may either be due to limitation of genetic potential or inadequacy of any of the environmental factor. Of the two approaches STCR fared better than Nutrient expert yield-wise, while economics was better with Nutrient expert indicating need for development of location specific values/factors.

Similarly, nutrition strongly influences maize performance, and in that response to targeting yield through nutrition was phenomenal and achievable. Witt *et al*. (2006) reported that highest yield ranged from 9.4 t ha^{-1} in Lampung to 13.7 t ha^{-1}in Central Jawa of Indonesia which they considered close to the environment genetically simulated with hybrid maize. By following SSNM technique in the Southern dry zone of Karnataka, Biradar and Jayadeva (2013) at MARS, Bengaluru, obtained 9.77 t ha yield against a yield target of 10 t ha^{-1} (while, 4.04 t ha^{-1} with state recommendation) with hybrid NAH 1137 (Hema), at MARS, Dharwad, Joshi *et al*. (2018) obtained 9.88 t ha^{-1} with cultivar S 6668 against a yield target of 10 t ha^{-1}, and in Northern dry zone, Pagad *et al*. (2018) obtained still higher yield of 12.83 t ha^{-1} against a yield target of 14 t ha^{-1}. In North eastern dry zone, Vikram *et al*. (2015) reported advantage of SSNM with 95.5% yield realization with 10 t ha^{-1} yield target. During *rabi*/summer the set yield targets (6, 8 and 10 t ha^{-1}) were achieved with 92.46 % efficiency with 10 t ha^{-1} target (9246 kg ha^{-1}) in cv. RCRMH 2, a heat stress tolerant cultivar (Swetha, 2021).

With the evolution of new and highly responsive and potential cultivars in cotton for commercial use the set yield target has also almost seen four-fold increase over the targets set initially (1.2 to 6 t ha^{-1}) (Table 12). Trial on farmers' field with SSNM for a yield target of 4 t ha^{-1} in TBP irrigation command was found achievable (Chittapur *et al*., 2017). Further, studies with still higher yield target (5 t ha^{-1}) with SSNM and nutrient supplementation for leaf reddening revealed the possibility of 5246 kg ha^{-1}, however targets were elusive with delay in sowing irrespective of genotypes used (Pyati *et al.,* 2017 and Hosamani, 2017).

Table 10. Effect of pulse magic on the performance of pulses in Karnataka

Crop	Treatment	Seed yield (t ha^{-1})	Net returns (₹ ha^{-1}) (B:C)	Source
Pigeonpea (100 demo/40 ha)	Pulse magic	1.55 (20%)*	60650 (3.46)	Patil *et al.* (2021)
	Control	1.29	49450 (3.00)	
Blackgram (25 demo/10 ha)	Pulse magic	1.06 (20%)	48760 (1.81)	Patil *et al.* (2018a)
	Control	0.87	40250 (1.62)	
Greengram (100 demo/40 ha)	Pulse magic	0.91	11792 (1.46)	Patil *et al.* (2018b)
	Control	0.75	715030)	

* Per cent increase over control, demo - demonstrations

Table 11. Effect of nutritional approaches for targeted yields in drill sown rice

Approaches/Organics	Grain yield target				S.Em.±
+ micronutrient	6 t ha^{-1}	7 t ha^{-1}	8 t ha^{-1}	Mean	
Nutrient Expert	5997^{d}	7086^{b}	7296^{a}	6793^{a}	Approach (N) : 103
STCR	6600^{c}	7061^{b}	7303^{a}	6988^{a}	Org.+Micro (M):103
No org./micro.	6954^{f}	6858^{d}	7137^{c}	6683^{b}	Target (T) :126
$FeSO_4$+ $ZnSO_4$+FYM	6543^{e}	7289^{b}	7462^{a}	7098^{a}	N x T : 179
	6298^{c}	7973^{b}	7299^{a}		M x T : 179

STCR – Soil test crop response

Table 12. Yield targets set and nutrients applied in cotton at different locations in India

Place	Yield Target (t ha^{-1})	Actual yield (t ha^{-1})	Fertilizer applied (N, P_2O_5, K_2O kg ha^{-1})
Rahuri	1.2-1.6	-	86:61:12 (STCR)
Coimbatore	2.5	-	50:0:0 (STCR)
Siruguppa	2.5	2.3	130:70:120 (SSNM)
Dharwad	3	3.22	217:59:148 (SSNM)
Raichur	4	4.27	195:100:200
Yadgir	4.5	5.14	272:150:62 (STCR)
TBP,	5	4.38	400:140:142.5(SSNM)
Karnataka	5	5.25	400:105:190 (SSNM)
UKP, Karnataka	6	4.27	480:168:171 (SSNM)

d. Need for secondary and micronutrients

Further, targeting yield with major nutrients alone is often not enough. For instance, in cotton, yields are often restricted by inadequate uptake of other nutrients caused by environment under higher targets (low temperature induced leaf reddening), and in rice particularly under DSR system,supply of micronutrients becomes critical. Santhosh *et al*. (2015) reported that leaf reddening index was significantly reduced with higher NPK fertilizers (150% RDF) and also with foliar spray of $MgSO_4$ + KNO_3 thrice combined with initial soil application of $MgSO_4$@ 25 kg ha^{-1}. In UKP irrigation command, Shivaraja (2015) obtained 4209 kg ha^{-1}seed cotton yield and low leaf reddening index (LRI - 0.69, 1.07 and 1.72 at 60, 90 and 120 DAS, respectively) with basal application of $MgSO_4$@ 25 kg ha^{-1} along with foliar spray of $MgSO_4$ + 19:19:19 @ 1% each for leaf reddening management (LRM) which was significantly superior over control with no LRM practices (3893 kg ha^{-1}, and high LRI 0.78, 1.25 and 1.84 at 60, 90 and 120 DAS, respectively). Honnali and Chittapur (2017) suggested use of 25% extra RDF with N in four splits along with soil application of 25 kg ha^{-1} $MgSO_4$ at planting followed by foliar spray thrice each of 1.0% $MgSO_4$ and 19:19:19 NPK at 80, 105 and 130 DAS coinciding with square formation, peak flowering and boll development which recorded lower scores for leaf reddening (0.67) and higher seed cotton yield (2.07 t ha^{-1}), sustainability yield index (90.59%) and economics (₹ 73,630 ha^{-1} and 2.65 net returns and B:C ratio, respectively) in comparison to application of recommended dose of fertilizer (0.87, 1.63 t ha^{-1}, 70.41%, ₹ 57,380 ha^{-1} and 2.38, respectively). A SSNM based nutrition (400:105:190 NPK kg ha^{-1}) for yield target of 5 t ha^{-1} along with additional fertilization of 25 $MgSO_4$ to soil and 1% each of 19:19:19, $MgSO_4$ and KNO_3 at flowering, boll development and boll bursting stage enabled higher seed cotton yields (5349 kg ha^{-1}) and higher monetary benefits (Chittapur *et al*., 2020) with no or negligible leaf reddening, moderate sucking pest incidence and better residual soil fertility status (Hosamani, 2017) (Table 13).

In drill sown rice, need for micronutrients is far more serious than in transplanted rice to achieve potential yields. In an experiment conducted in Tunga Bhadra project irrigation command of Karnataka, across cultivars and seed rates, combined application of $FeSO_4$ and $ZnSO_4$ both basally to the soil and subsequently to the foliage recorded higher grain yield during rainy and summer seasons (Table 14) followed by application of $ZnSO_4$ alone, with an yield improvement to the tune of 9.82 and 22.46 per cent during rainy and summer seasons respectively over no application of micronutrient. Response of cultivars to micronutrient application was identical irrespective of the seasons (Shubha, 2017).

Table 13. Seed cotton yield (kg ha^{-1}) as influenced by targeted yields and leaf reddening management practices

Targets	S_1	S_2	S_3	S_4
3 t ha^{-1}	3401^{i}	3452^{hi}	3509^{hg}	3568^{g}
4 t ha^{-1}	4407^{f}	4487^{e}	4517^{ed}	4568^{d}
5 t ha^{-1}	5148^{c}	5212^{cb}	5275^{b}	5349^{a}
S.Em±	87			

Note : S_1: Vermicompost @ 2.5 t ha^{-1}, S_2: S_1 + $MgSO_4$@ 10 kg ha^{-1} in seed line, S_3: S_1 + $MgSO_4$@ 25 kg ha^{-1} in seed line, and S_4: S_1 + $MgSO_4$@ 25 kg ha^{-1} in seed line + foliar nutrition of 1% $MgSO_4$ + 19:19:19 + 1% KNO_3 (thrice)

Table 14. Grain yield (kg ha^{-1}) response of rice genotypes to micronutrients during rainy and summer seasons

Rainy season	GGV 0501	MTU 1010	BPT 5204	Mean	
Control	4500^{fg}	5396^{b-d}	4158^{g}	4685^{c}	S. Em.±
$FeSO_4$*	4870^{ef}	5749^{ab}	4537^{fg}	5052^{b}	Micronutrient: 74
$ZnSO_4$	5315^{cd}	6085^{a}	4830^{ef}	5410^{a}	Interaction : 128.5
$FeSO_4$ + $ZnSO_4$	5663^{a-c}	6052^{a}	5128^{de}	5614^{a}	
Summer	GGV 0501	RNR15048	BPT 5204	Mean	
Control	4802^{cd}	3779^{g}	412^{fg}	4234^{c}	S. Em.±
$FeSO_4$*	5358^{b}	4163^{fg}	4198^{e-g}	4573^{b}	Micronutrient : 96
$ZnSO_4$	5907^{ab}	4699^{c-e}	4311^{d-f}	4972^{ab}	Interaction : 167
$FeSO_4$ + $ZnSO_4$	6029^{a}	507^{bc}	4451^{d-f}	5185^{a}	

*each to soil @ 25 kg ha^{-1} + foliar @ 0.5% at 15 and 30 DAS

Means followed with same alphabet(s) in a column do not differ significantly by DMRT (P=0.05)

2. Irrigation and fertigation

A few traditional rainfed oil seed and pulse crops revealed realization of tremendous yielding potential under drip irrigation. For instance, response of pigeonpea to irrigation is spectacular. Crop found to require 35-40 cm waterduring its entire growth period. Scheduling of irrigation at 75% CPE with wider spacing of 120 cm x 60 cm (2869 kg ha^{-1}) recorded significantly higher seed yield (Table 15) (Rathod, 2021). Under drip irrigation, farmers realized as high as 35-40 q ha^{-1} from May last week planted crop in the North-eastern transition zone of Karnataka. In such a system, yields further improved (3340 kg ha^{-1}) with drip fertigation of recommended N and P_2O_5 (25:50 kg ha^{-1}) in five splits using water soluble fertilizers (Table 16) (Vanishree *et al*., 2019). Similarly, drip irrigation in safflower is new but has tremendous potential. Normal rainfed safflower yield is 300-500 kg^{-1}ha. At Hyderabad, on beds 1/2 m wide with lateral in the centre and drips at 40 cm distance produced 1731-1876 kg^{-1} ha seed yield with 200 -228mm water (Ranjitha, 2018). At Sholapur, 3 irrigations (drip) at rosette elongation, branching and 50% flowering at 100 CPE (232mm) recorded 2638 kg^{-1} ha seed yield (Khadtare *et al*., 2018), while Maharashtra farmers' claim 3750 kg^{-1} ha under drip on broad bed.

In rice, among different irrigation scheduling, alternate wetting and drying (AWD) besides higher yields (Mahender kumar and Ravindra Babu, 2016 and Jagadish, 2018) helps to mitigate GHGs emission by 26.91 per cent than continuous submergence along with 25.51 per cent saving of total water over continuous submergence (Jagadish, 2018, Jagadish *et al*., 2019) (Table 5). The per cent increase in grain yield with AWD was 3.70, 17.21 and 23.05 per cent over farmers' method, saturation and critical stage of irrigation. Further, drip irrigation with scheduling at 1.50 IW/CPE ratio (5060 kg ha^{-1}) supplied with 125% recommended dose of nitrogen (RDN) through fertigation recorded significantly higher (5049 kg ha^{-1}) grain yields (Table 17).

Now, drip irrigation is a rule than exception in sugar cane also. In earlier studies, cane yield was higher (153.6 and 144.2 t ha^{-1} in pre-seasonal and seasonal crops, respectively) under drip irrigation with 60-180-60 cm with recommended practices and weekly fertigation with water soluble fertilizers. While, conventional practice of furrow irrigation and urea as N source recorded significantly lower yields (105.4 and 117.2 t ha^{-1} in pre-season and seasonal crops, respectively) during both planting seasons (Chandrashekhar, 2009). Subsequent studies revealed that planting in paired row of 3'-6'-3'/ 2'-4'-2', wide row of 4' or 5' and pit proved superior compared to normal method (S. S. Nooli, Personal Communication). Green manuaring of pure or mixed stands of green/grain crops helped increasing the cane and sugar yield. Further, fertigation at weekly, fortnightly or monthly intervals did not reveal any significant variation, however, significantly higher cane yield and nutrients uptake were recorded with ratoon under monthly

Table 15. Effect of irrigation scheduling and plant spacing on the performance of pigeonpea

	Seed yield		Gross returns	Net returns	B:C Ratio
	g plant^{-1}	kg ha^{-1}	(₹ ha^{-1})	(₹ ha^{-1})	
Irrigation level (I)					
50% CPE (I_1)	110.6	2168	130069	83336	2.78
75% CPE (I_2)	132.6	2509	150534	103801	3.22
100% CPE (I_3)	124.9	2401	144061	97328	3.08
S.Em.±	1.9	33	2119	2119	0.06
C D at 5%	7.5	130	8323	8323	0.21
Spacing (S)					
120 x 30 cm (S_1)	102.3	2215	132929	86137	2.84
120 x 45 cm (S_2)	121.6	2368	142114	95393	3.04
120 x 60 cm (S_3)	144.1	2494	149620	102934	3.20
S.Em.±	1.6	38	1665	1665	0.06
C D at 5%	4.8	118	5101	5101	0.18

CPE: Cumulative pan evaporation

Table 16. Response of transplanted pigeonpea to drip irrigation and fertigation

Treatments	Seed yield		Harvest index	Net returns	B:C Ratio
	g plant^{-1}	Kg ha^{-1}		(₹ ha^{-1})	
No irrigation, NF to soil	80.2	1042	0.23	33100	2.37
Surface irrigation, NF to soil	127.1	1427	0.26	53999	3.20
Drip irrgn., NF to soil (3 splits)	215.1	2006	0.27	76368	3.25
Drip irrgn., NF to soil (4 splits)	234.3	2170	0.28	82068	3.20
Drip irrgn., NF to soil (5 splits)	247.3	2170	0.29	91348	3.64
Drip irrgn., SF to soil (3 splits)	301.2	2290	0.32	114628	3.79
Drip irrgn., SF to soil (4 splits)	320.1	3010	0.34	124153	4.01
Drip irrgn., SF to soil (5 splits)	360.5	3340	0.46	141983	4.40
CD (P=0.05)	13.1	181	0.09	4039	0.14

Note: Irrgn. –Irrigation, NF – Normal fertilizer, SF – Soluble fertilizer, fertigation at 30, 45, 60 (3 splits), and 75 (4 splits) and 90 (5 splits) days after transplanting

Table 17. Performance of drill sown rice as influenced by IW/CPE ratio and fertigation level

IW/CPE Fertigation	Grain yield (kg ha^{-1})	N uptake (kg ha^{-1})	NUE (kg kg^{-1})	Net Returns (₹ ha^{-1})	Total water used (mm)	WUE (kg ha mm^{-1})
IW/CPE						
0.75	4431^{b}	85.2^{d}	71.4^{b}	35589^{b}	733.7^{d}	7.69^{a}
1.00	4599^{b}	91.1^{c}	73.6^{b}	38093^{b}	800.6^{c}	7.14^{ab}
1.25	4875^{a}	107.2^{b}	78.9^{ab}	42324^{a}	882.2^{b}	6.78^{b}
1.50	5060^{a}	130.3^{a}	83.7^{ab}	45105^{a}	1044.3^{a}	5.76^{c}
S.Em±	58	0.8	2.6	988	15.0	0.15
Fertigation(F)						
F_1	4678^{b}	96.6^{c}	76.1^{ab}	39386^{b}	865.2	6.69^{ab}
F_2	4914^{ab}	111.5^{b}	78.4^{ab}	43157^{ab}	865.2	7.04^{a}
F_3	5049^{a}	122.7^{a}	80.5^{a}	45231^{a}	865.2	7.22^{a}
F_4	4324^{c}	83.0^{d}	72.4^{b}	33336^{c}	865.2	6.42^{b}
S.Em±	90	1.8	2.5	1478		0.14

F_1: 75 % RDN F_2: 100% RDN F_3: 125% RDN, F_4: 150% RDN NUE: Nitrogen use efficiency WUE: Water use efficiency

interval. Single eye bud seedling at 180 x 60 cm recorded significantly higher cane yield of 162 t ha^{-1} followed by planting at 180 x 90 cm (154 t ha^{-1}), which are comparable with national recommendation of 150 x 60 cm (150 t ha^{-1}) with seed cost advantage, while conventional method with three budded sets recorded significantly lower yield (102 t ha^{-1}).

Future thrusts

Grower is the leader in harnessing genetic crop potential better than anybody else on farm situations and for him knowledge on crop biology and ecology is a great asset in realization of crop potential in the changing climate and deteriorating natural resource base.

- Simple manipulation of seed bed, seed, plant architecture, precision in use of costly inputs like nutrients, water, fuel etc. will continue to hold our attention as long as land based agriculture continues, and of course there is no alternative to it though we speak of vertical farming, soil less culture etc.
- Crop economic product or yield is like a conceived baby in the womb with lot of uncertainties till the final stage. Environment matters a lot in crops,proper understanding and manipulation whenever possible to the advantage of crop would be of great help and in that smart practices particularly of both crop and environment assume significance in seed to seed time line.
- With other technical graduates and doctors entering farming, besides the rural layman becoming more technologically aware and proficient in using smart gadgets, in days to come agriculture would become and will have to become more efficient and proficient and farmers already are in a switching mode.
- Global agriculture is witnessing waves of revolutions in areas of crop production due to the interventions of the state of the art technologies such as bioinformatics, geoinformatics, nanotechnology etc. Remote sensing and artificial intelligence will be part of this new and evolving agriculture and, therefore, certainly our focus should be towards smart and sustainable agriculture involving these developments. International gatherings on these themes and camaraderie among growers, technocrats and scientists would help our march in this 4th agricultural revolution.

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