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PRECISION WATER AND NITROGEN MANAGEMENT FOR ENHANCING GROWTH AND YIELD OF AEROBIC RICE UNDER DRIP SYSTEM

B. BHAVANA[1], P. LAXMINARAYANA[2], R. MAHENDER KUMAR[3], K. SUREKHA[4], S. NARENDER REDDY[5] and M. YAKADRI[1]

[1]Department of Agronomy, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad
[2]Department of Agronomy, Agricultural Research Institute, Main Farm, Rajendranagar, Hyderabad
[3]Division of Agronomy, IIRR (ICAR), Rajendranagar, Hyderabad
[4]Department of Soil Science, IIRR (ICAR), Rajendranagar, Hyderabad
[5]Agricultural college, Jagtial

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ABSTRACT

A Field experiment was conducted at Indian Institute of Rice research (IIRR) during *rabi* season of 2020 and 2021, with an objective to study the effect of precision water and nitrogen management on growth and yield of aerobic rice under drip system. Treatments included three irrigation management methods- {I_1 (Drip irrigation 1.5 Epan in Flat bed system); I_2 (Drip irrigation 1.5 Epan in Raised bed system) and I_3 {Surface irrigation (up to saturation)}} and four precision nitrogen management practices- N_1 {Recommended practice (RDF)-(120:60:40 N P K kg ha^{-1})}; N_2 {Green seeker (Optical sensor) based N application}; {N_3 (LCC based N application) and N_{4-} (No Nitrogen)} replicated thrice. Results of experiment revealed that, among all the treatments, surface irrigation with LCC based nitrogen management was more beneficial in enhancing the growth and yield of aerobic rice. Among irrigation methods, higher values of growth parameters (mean of 2020 and 2021) at harvest such as, plant height (82.4 cm), leaf area index (3.98), dry matter accumulation (8344 kg ha^{-1}), tillers m^{-2} (239), grain yield (4171 kg ha^{-1}) and straw yield (4791 kg ha^{-1}) were observed in surface irrigation which was on par with drip irrigation under raised beds (76.8 cm, 3.66, 7852 kg ha^{-1}, 221, 3738 kg ha^{-1} and 4209 kg ha^{-1}). Higher values of plant height (85.5 cm), leaf area index (4.46), dry matter accumulation (8802 kg ha^{-1}), tillers m^{-2} (233), grain yield (4230 kg ha^{-1}) and straw yield (4885 kg ha^{-1}) were recorded under LCC based N application followed by recommended practice among nitrogen management practices. The results of the study implied that, cultivating rice by adopting aerobic system under drip irrigation along with precision nitrogen management with LCC and greenseeker provides an opportunity to save the resources like water and nutrients to produce optimal yields.

Key words: Aerobic rice, Precision management, Yield, Nitrogen, Drip irrigation, Raised beds, LCC and Greenseeker.

Every third person on earth consumes rice everyday in one form or the other and about 90% of the total rice produced is consumed in Asian countries. In India, rice occupies about 44.16 M ha of area producing about 116.48 M t with productivity of 2.63 t ha^{-1}. Telangana state contributes 1.93 M ha area with a production of 6.67 M t and an average productivity of 3452 kg ha^{-1} during 2018-19 (DES Statistics 2019-20). According to a report (Postel, 1998) global rice requirement by 2025 will be 800 M t. At the moment, rice production is less than 600 M t and a deficit of 200 M t need to be produced by increasing productivity per unit area against the diminishing resources.

Rice is a water-intensive and least water-use efficient crop. There is an urgent need to search for an alternate irrigation system that can reduce water requirement without much reduction in yield. Aerobic rice is such technology which was designed to enhance water use efficiency, by growing in non-puddled, non-flooded fertile soils which saves water by eliminating continuous seepage and percolation, land preparation and reducing evaporation. Compared to lowland rice, water and labour requirements for aerobic rice are lower to an extent of 50 and 55% respectively (Bouman *et al.*, 2002). Drip irrigation in addition is a water saving system in which, precise amount of water is applied to the soil surface directly to plant root zone for improving water use efficiency.

Land configuration plays a major role in minimizing soil erosion and improving water and nutrient use efficiency of field crops (Vishuddha *et al.*, 2022). Conventional rice growing layouts and practices have several disadvantages like soil structural degradation,

Email: bhavanabudiga28@gmail.com

poor water management and waterlogging of drill sown rice and of crops grown in rotation with rice and restrictions of cropping sequence flexibility (Beecher *et al.* 2006). Raised bed systems can be an alternative solution to reduce waste of water use and adapt to climate conditions with low and erratic rainfall. It has been proven to be able to save water, as well as to improve the stability of soil aggregates. (Kusnarta *et al.*, 2021).

For most soils of the country, nitrogen use efficiency of rice is only about 30 to 40% and about 1/3 rd of applied N is lost by different N losses (Abrol *et al.,* 2007). Research has been oriented more towards finding means and ways to apply fertilizer nitrogen in real-time using crop demand-driven and field-specific needs. A simple and quick method for estimating the plant nitrogen demand is LCC (leaf colour chart). LCC will provide indirect assessment of leaf N status (Peng *et al.,* 1995). Leaf colour chart though it provides instantaneous results in scheduling nitrogen application, but they do not take into account the biomass of crop. Spectral vegetation indices such as normalized difference vegetation index (NDVI) are useful for indirectly obtaining information such as photosynthetic efficiency, productivity potential and potential yield (Raun and Johnson, 1999) which can be measured by optical sensors. Greenseeker optical sensors use visible and NIR spectral response from plant canopies to detect N stress.

Not much work has been carried out on raised bed and use of precision management tools in aerobic rice under drip irrigation system. In view of the above facts, the present experiment entitled **"Precision water and nitrogen management in aerobic rice (*rabi*) under drip system"** has been proposed.

MATERIAL AND METHODS

The field experiment was conducted during *Rabi* 2020-2022 at Indian Institute of Rice Research (IIRR), Rajendranagar, Hyderabad, Telangana. The geographical location of the experimental site was 17^0 19" N and 78° 23" E Longitude with an altitude of 542 m above mean sea level. Experimental soil was clay loam in texture, moderately alkaline in pH (8.22), non-saline in reaction (0.23 dS m^{-1}), low in organic carbon content (0.46%), low in nitrogen (184.2 kg ha^{-1}), medium in phosphorus (33.4 kg ha^{-1}) and high in potassium (482.7 kg ha^{-1}). Rice variety selected for the study was DRR Dhan-42 with duration of 125 days. All agronomic practices were carried out as per the recommendations. Direct seeding of dry seeds @ 60kg ha^{-1} was done manually. Pre emergence application of pendimethalin @ 0.50 kg ha^{-1} at 2 days after sowing and post emergence application of bispyribac sodium 11% SC spray @ 200 ml $acre^{-1}$ at 20 days was done. Crop was weeded manually twice at 25 and 45 days after sowing. The treatments were divided into horizontal and vertical strips with Strip plot design. The horizontal strip was further divided into three irrigation management methods and vertical strips were divided into four nutrient management methods as detailed below:

Horizontal Strips: (PRECISE WATER MANAGEMENT)

I_1: DRIP irrigation 1.5 Epan in Flat bed system

I_2: DRIP irrigation 1.5 Epan in Raised bed system

I_3: Surface irrigation **(**up to saturation)

Vertical Strips: (PRECISE NITROGEN MANAGEMENT)

N_1: Recommended practice (RDF)- (120:60:40 N P K kg ha^{-1})

N_2: Green seeker (Optical sensor) based N application

N_3: LCC based N application

N_4: No Nitrogen

The raised beds were freshly prepared (during both years) mechanically by a bed planter (80 cm wide), separated by furrows of 20 cm wide and 20 cm deep. Direct seeding of dry seeds manually carried out during both the years at 20 cm x 10 cm spacing wherein 4 rows are accommodated in each bed and gap filling was done at 10 DAS. To separate the effect of water management from that of the raised beds themselves, the same row spacing was used in all the treatments.

Irrigation management

The irrigation water was applied through drip system in raised and flatbed treatments on the basis of pan evaporation (PE) data obtained from (USWB open pan evaporation) installed at the Agroclimatic Research Centre, ARI, Rajendranagar, Hyderabad. Irrigation was given from 10 days after sowing to 8 days before harvest through drip irrigation. First irrigation was given immediately after sowing and subsequent irrigations were scheduled once in 2 days. The quantity of applied water to each treatment was measured with the help of water meter. During rainy days, the volume of water applied to each treatment was adjusted for the effective rainfall received. Separate valves were provided to drip system for regulating water supply to each plot. In surface irrigation treatment, irrigation was given above field capacity daily avoiding flooding. To prevent seepage flows between aerobic and surface irrigated plots, the plots were separated by a strip of bare soil of 2 m width from the aerobic drip plots.

The quantity of water was calculated as follows:

$$\text{Application rate (mm per hr)} = \frac{Q}{DL \times DE}$$

Whereas

Q = Dripper discharge (liters h^{-1})

D_L = Distance between lateral spacing (m)

D_E = Distance between dripper (emitters) spacing (m)

Irrigation time for each treatment was calculated using the following formula.

$$\text{Irrigation (minutes)} = \frac{\text{Epan (mm)} \times 60}{\text{Application rate (mm per hr)}}$$

Nutrient management

Basal soil application of $ZnSO_4$ @ 25 kg ha^{-1}, $FeSO_4$ @ 50 kg ha^{-1} and $MgSO_4$ @ 2 kg ha^{-1} was applied to prevent Fe and Zn deficiency. Also foliar sprays of 0.5% $ZnSO_4$ and 1 % $FeSO_4$ was taken up at tillering and panicle initiation stages. The recommended dose of fertilizer @ 120-60-40 kg NPK ha^{-1} was applied through Urea, Single Super Phosphate and Muriate of Potash. For N_1 treatment nitrogen was applied as 20 % at 15 DAS, 30% each at (tillering and Panicle Initiation) and 20% at flowering stage. Recommended dose of nitrogen was applied along with irrigation water through fertigation in drip irrigated plots. Nitrogen @ 20 kg ha^{-1} was applied as basal and remaining dose (15 kg ha^{-1} each time) was applied based on the treatments (N_2 and N_3) that included precise nitrogen management tools like Green seeker and Leaf colour chart, as and when the threshold levels {(NDVI-0.40, 0.70 and 0.65 for Initial, Crop development and Reproductive stages respectively) (Prashant, 2017) and (LCC threshold value-3)} have reached. Nitrogen was avoided for N_4 treatment (Zero Nitrogen) Details regarding the time and amount of nitrogen fertilizer applied according to treatments are furnished in Table 1.

N application based on LCC observation

The topmost fully expanded leaf from each hill was selected and leaf colour was compared by placing the middle part of the leaf on LCC and the leaf colour was observed. Whenever the green colour of more than 5 out of 10 leaves were observed equal to or below a set critical limit of LCC score, nitrogen was applied as per the treatment. LCC readings were taken from 21 DAS to 50 % flowering. The leaf was not detached or destroyed. The average LCC reading were determined for each treatment. Readings were taken in the morning (8-10 AM) under the shade of body in order to avoid the influence of sun light as it may reflect the LCC colour.

N application based on Greenseeker observation

Normalized Difference Vegetative Index (NDVI) is a measure of the total biomass and greenness of leaves was measured using greenseeker.

$$\mathbf{NDVI = (NIR_{ref} - RED_{ref})/ (NIR_{ref} + RED_{ref})}$$

Where, NIR_{ref} or RED_{ref} represents reflectance in the near infrared and red wavebands.

NDVI values can range from 0.00 to 0.99. Higher the reading, healthier the plant. The value 0 represents absence of vegetation. The peak value within the N-rich strip (RDF) and value typical of N_2 treatment were used as two inputs and then referenced on the fertilizer estimation chart to determine the application rate of nitrogen. These spectral properties were measured at weekly interval starting from 21 days after sowing (DAS) to 50 % flowering. Whenever the observed NDVI values fall below the threshold value, nitrogen was applied immediately to meet the N requirement.

Observations on plant height, leaf area, tillers, dry matter production, grain yield and straw yield during maturity stage were recorded. Five hills per plot were randomly marked with wooden sticks and labelled for recording observations.

Table 1. Quantity of nitrogen applied in different treatments during *rabi*, 2020-21 and 2021-22

Treatment			2020-21												2021-22												Total Nitrogen applied (kg ha^{-1})	
			Time of application (DAS)																									
		Basal	21	28	35	42	49	56	63	70	77	84	91	98	21	28	35	42	49	56	63	70	77	84	91	98	2020	2021
I_1	N_1	24					36			36		24							36			36		24			120	120
	N_2	20	15		15		15		15	15		10				15	15		15		15	15		15			110	105
	N_3	20		15	15	15		15		15	15					15		15	15	15		15	15				110	110
	N_4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0
I_2	N_1	24					36			36		24							36			36		24			120	120
	N_2	20		15		15	15		15	15	15						15	15		15		15	15	10			115	100
	N_3	20	15		15		15	15		15		15				15		15		15	15		15		10		105	110
	N_4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0
I_3	N_1	24					36			36		24							36			36		24			120	120
	N_2	20	15		15		15	15		15		10				15		15	15		15		15		15		110	105
	N_3	20	15		15		15	15		15							15	15	15		15			15			95	95
	N_4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0

I_1: DRIP irrigation 1.5 Epan in Flat bed system
I_2: DRIP irrigation1.5 Epan in raised bed system
I_3: Surface irrigation (upto saturation)
N_4: No Nitrogen
N_1: Recommended practice (RDF)- (120:60:40 NPK kg ha^{-1})
N_2: Green seeker (Optical sensor) based N application
N_3: LCC based N application

RESULTS AND DISCUSSION

Effect of precision water and nitrogen management on growth parameters of aerobic rice

The data depicted in the Table 2 showed significant variation in growth parameters of rice v*iz*., plant height, leaf area index (LAI), tillers m^{-2} and dry matter production (DMP). Higher plant height at harvest (82.4 cm) was recorded with Surface irrigation (up to saturation) which was at par with DRIP irrigation 1.5 Epan in Raised bed system (76.8 cm) and lowest (71.6 cm) with DRIP irrigation 1.5 Epan in Flat bed system. Surface irrigation was (8.1-9.5) % and (8.9-20) % superior in plant height over drip irrigation treatments, i.e., I_2 and I_1 treatments respectively. Higher plant height recorded with surface irrigation (upto saturation) might be due to higher moisture availability which improved cell division and elongation resulting in higher plant height compared to drip irrigation. Similar results were reported by Venkataravana (2019). Further, relatively higher plant height on raised beds than flat beds might be due to the good anchorage of roots. Similar findings were recorded by Anusha *et al.* (2015). Among all the nitrogen management practices, LCC based N application treatment recorded higher plant height of 85.5 cm which was on par with {Recommended practice (RDF)- (120:60:40 N P K kg ha^{-1})} (82.4 cm) and Green seeker (Optical sensor) based N application (80.9 cm) and lowest plant height was recorded with the No Nitrogen (58.9 cm). Increase in plant height of aerobic rice under precision nitrogen management based on LCC might be due to fact that, applied nitrogen matched crop nitrogen demand, which resulted in higher uptake of nitrogen, involved in cell division and elongation, that resulted in increased inter nodal elongation and enhanced vegetative growth and in turn plant height. Similar increase in plant height with precision nitrogen management was reported by Moharana *et al.* (2017).

Higher LAI at harvest (3.98) was recorded with Surface irrigation (up to saturation) which was at par with DRIP irrigation 1.5 Epan in Raised bed system (3.66) and lowest was recorded with DRIP irrigation 1.5 Epan in Flat bed system (2.70). The higher LAI with I_3 treatment might be due to continuous moisture supply throughout the crop growth period, which increased plant height and number of tillers consequently resulted in more leaf area per land area. While lowest LAI under flatbed irrigation might be due to moisture stress conditions probably due to more evaporation losses which affected the leaf cell expansion. These findings are in agreement with Duary and pramanik (2019) and Kalyan *et al.* (2021). Among all the nitrogen management practices, highest LAI at harvest was noticed with LCC based N application (4.46) which was on par with Recommended practice (RDF)- (120:60:40 N P K kg ha^{-1}) (4.22) and Green seeker (Optical sensor) based N application (3.85). While lowest was recorded with the No Nitrogen (1.27). Application of nitrogen based on the crop demand using LCC increased leaf area per unit area there by increased leaf area index. This might be due to sufficient availability of nitrogen at right time for producing larger cells with thinner cell walls thereby resulting in efficient cell division and elongation, ultimately producing higher photosynthetic area per unit land area (Mude *et al.*, 2021). These results are supported by findings of Xiang *et al.* (2020).

Higher number of tillers m^{-2} at harvest (239) were recorded with Surface irrigation (up to saturation) which was at par with DRIP irrigation 1.5 Epan in Raised bed system (221) and lowest (194) with DRIP irrigation 1.5 Epan in Flat bed system. Higher tiller number recorded with surface irrigation upto saturation might be due to, more available soil moisture which resulted in favourable root growth and absorption of nutrients consequently resulted in production of more tillers per hill. Further more, fertigation at frequent interval coincided with nutrient demand enable to supply required quantity of nutrients at all the growth stages without moisture stress which resulted in higher tiller number. Similar results were reported by Kusnarta *et al.* (2021). Among nitrogen management practices, higher number of tillers m^{-2} at harvest (233) were registered LCC based N application which was on par with Recommended practice (RDF)- (120:60:40 N P K kg ha^{-1})}(229) and Green seeker (Optical sensor) based N application (225) while, lowest number of tillers m^{-2} (186) with the No Nitrogen. Increase in number of tillers m^{-2} was observed under precision nitrogen management based on LCC, this led to increased availability of nitrogen at all stages, which enhanced uptake of nitrogen and other nutrients in sufficient quantity that enabled crop to put forth higher biomass and enhanced tillering capacity of rice plant. The results are in agreement with Hemalatha *et al.* (2020).

Dry matter accumulation was slow at early vegetative stage and thereafter it increased progressively with advance in age of the crop up to harvest. Higher drymatter at harvest (8344 kg ha^{-1}) was recorded with Surface irrigation (up to saturation)}which was at par with DRIP irrigation 1.5 Epan in Raised bed system (7852 kg ha^{-1}) and lowest (6997 kg ha^{-1}) was recorded with DRIP irrigation 1.5 Epan in Flat bed system. Among all the nitrogen management practices, higher drymatter (8802 kg ha^{-1}) was noticed with LCC based N application which was on par with Recommended practice (RDF)- (120:60:40 N P K kg ha^{-1}) (8490 kg ha^{-1}) and Green seeker (Optical sensor) based N application (8337 kg ha^{-1}) and lowest (5293 kg ha^{-1}) was recorded with the No Nitrogen.

Interaction effect between irrigation and nitrogen management practices on drymatter accumulation of aerobic rice was significant at harvest stage during both the years (Table 3 and Figure 1). Higher mean drymatter was recorded with treatmental combination of surface irrigation (upto saturation) with LCC based N application (9500 kg ha^{-1}) followed by surface irrigation with Green seeker based N application (9252 kg ha^{-1}) and surface irrigation with recommended practice of N application (RDF) (9214 kg ha^{-1}). While lowest mean drymatter was recorded with DRIP irrigation in Flat bed system with No Nitrogen application (5051 kg ha^{-1}).

Among all treatment combinations, surface irrigation with LCC based N application gave highest drymatter accumulation. This can be attributed to the continuous moisture availability with surface irrigation and supply of right quantity of nitrogen at right time with LCC based fertilizer application facilitating higher water and nutrient uptake coupled with possible reduction in transpiration rate and CO_2 exchange that resulted in increased production of photosynthates and their translocation to sink (Shekara *et al.,* 2010). Highest drymatter accumulation observed with LCC based N application was mainly due to synchronization of applied nitrogen with crop demand and supply. Also availability of nitrogen for longer time due to lower leaching losses of nitrogen with more splits lead to increased chlorophyll pigments. This in turn increased specific leaf weight and resulted in more light interception, root development, leaves development and plant height. This in turn resulted in better dry matter production and distribution in the plant like leaves, stem and panicle finally better yield and yield components. These results are in conformity with the findings of Subedi *et al*. (2019). Low dry matter production in flat bed might be due to higher moisture stress conditions that might resulted in reduction in cell division, cell volume, cell elongation, photosynthesis and biomass production (Ghosh and Singh*,* 2010). Relatively higher drymatter was recorded with raised bed method than flat bed method under drip irrigation. The better anchorage to the crop under raised beds leads to good crop growth and thus increases dry matter production of the crop.

Effect of precision water and nitrogen management on grain and straw yield of aerobic rice

The grain yield and straw yield were significantly influenced by precision water and nitrogen management (Table 2). Among irrigation treatments, higher grain yield (4171 kg ha^{-1}) was recorded with Surface irrigation (up to saturation) which was on par with (3738 kg ha^{-1}) DRIP irrigation 1.5 Epan in Raised bed system and both of them differed significantly with DRIP irrigation 1.5 Epan in Flat bed system (3360 kg ha^{-1}). In general, the Nitrogen management treatments did not differ significantly among themselves with respect to grain yield, but were significantly higher than the control (No Nitrogen). Highest grain yield (4230 kg ha^{-1}) was recorded with LCC based N application treatment which was at par with Recommended practice (RDF)- (120:60:40 N P K kg ha^{-1}) (4126 kg ha^{-1}) and Green seeker (Optical sensor) based N application (4061 kg ha^{-1}) and significantly lowest grain yield (2608 kg ha^{-1}) was registered with No Nitrogen. The percentage of 'N' saving under precision nitrogen management treatments N_3 (LCC based N application) and N_2 Green seeker (Optical sensor) based N application} was to the extent of (8.4-20.9 %) and (8.4-16.7 %) respectively compared to recommended practice. While yield advantage with LCC based N management was about (2.2-4.2) % compared to N_1 {Recommended practice (RDF)-(120:60:40 N P K kg ha^{-1})}.

Interaction effect between irrigation and nitrogen management practices on grain yield of aerobic rice was significant during both years (Table 4). Among all the interactions, highest mean grain yield was recorded with surface irrigation with Green seeker based N application (4813 kg ha^{-1}) followed by surface

Table 2. Effect of precision water and nitrogen management on growth parameters and yield of aerobic rice during r*abi* (Mean of 2020 and 2021)

	Plant height (cm)	Leaf area index	Tillers m^{-2}	Drymatter production (kg ha^{-1})	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Vertical plots: Irrigation management (I)						
I_1	71.6	2.70	194	6997	3360	4005
I_2	76.8	3.66	221	7852	3738	4209
I_3	82.4	3.98	239	8344	4171	4791
SE(m)±	2.0	0.13	6	126	144	149
CD (p=0.05)	7.6	0.52	25	493	566	583
Horizontal plots: Nitrogen management (N)						
N_1	82.4	4.22	229	8490	4126	4797
N_2	80.9	3.85	225	8337	4061	4644
N_3	85.5	4.46	233	8802	4230	4885
N_4	58.9	1.27	186	5293	2608	3014
SE(m)±	2.4	0.13	7	102	182	174
CD (p=0.05)	8.3	0.46	23	354	630	602
Interaction						
IxN						
SE(m)±	4.0	0.31	13	181	178	262
CD (p=0.05)	NS	NS	NS	631	648	NS
NxI						
SE(m)±	4.1	0.29	12	160	207	267
CD (p=0.05)	NS	NS	NS	517	699	NS

I_1: DRIP irrigation 1.5 Epan in Flat bed system
I_2: DRIP irrigation 1.5 Epan in Raised bed system
I_3: Surface irrigation (up to saturation)

N_1: Recommended practice (RDF)- (120:60:40 N P K kg ha^{-1})
N_2: Green seeker (Optical sensor) based N application
N_3: LCC based N application
N_4: No Nitrogen

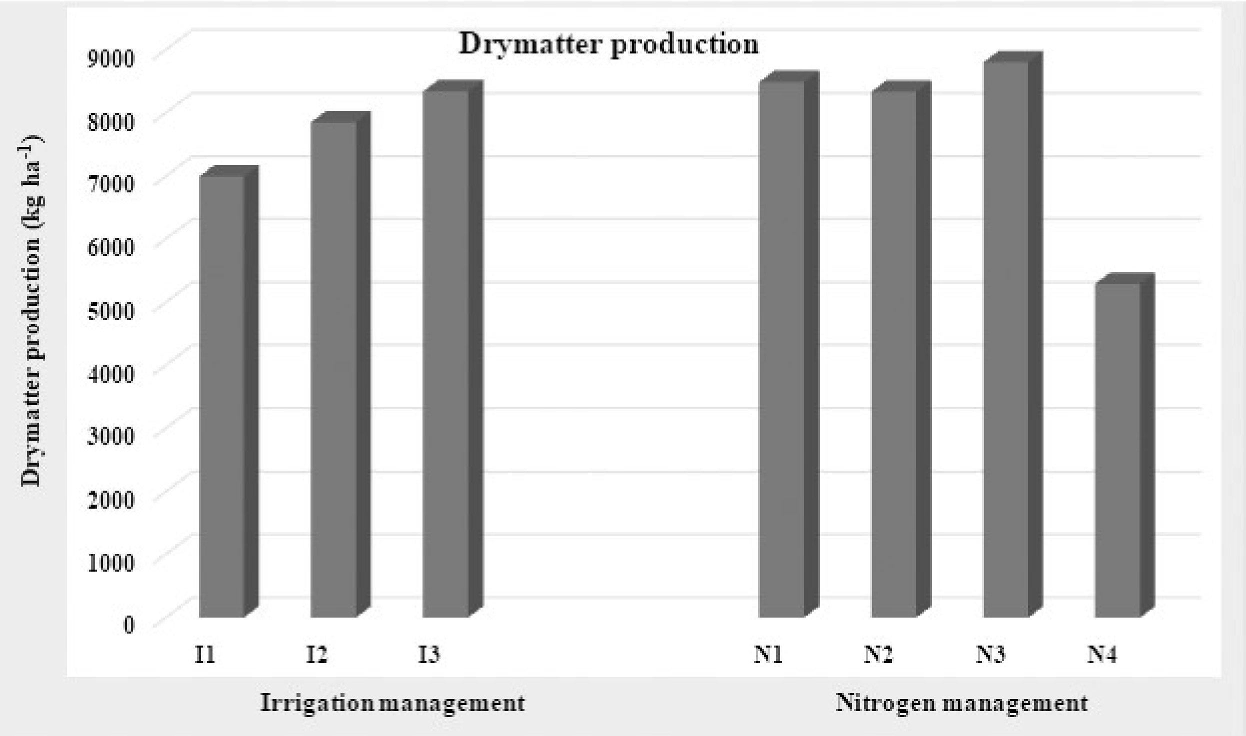
Table 3. Interaction effect of precision water and nitrogen management on mean drymatter production at harvest (kg ha^{-1}) of aerobic rice during *rabi* (Mean of 2020 and 2021)

Treatments	Nitrogen management				
Irrigation management	N_1	N_2	N_3	N_4	Mean
I_1	7799	7392	7744	5051	6997
I_2	8458	8367	9162	5419	7852
I_3	9214	9252	9500	5409	8344
Mean	8490	8337	8802	5293	
	I	N		I at same N	N at same I
SEm+	126	102		181	160
CD at p-0.05	493	354		631	517

I_1: DRIP irrigation 1.5 Epan in Flat bed system
I_2: DRIP irrigation 1.5 Epan in Raised bed system
I_3: Surface irrigation (up to saturation)

N_1: Recommended practice (RDF)- (120:60:40 N P K kg ha^{-1})
N_2: Green seeker (Optical sensor) based N application
N_3: LCC based N application
N_4: No Nitrogen

Figure 1. Drymatter production of aerobic rice at harvest as influenced by precision water and nitrogen management during *rabi* (mean of 2020 and 2021)



I_1: DRIP irrigation 1.5 Epan in Flat bed system
I_2: DRIP irrigation 1.5 Epan in Raised bed system
I_3: Surface irrigation (up to saturation)

N_1: Recommended practice (RDF)- (120:60:40 N P K kg ha^{-1})
N_2: Green seeker (Optical sensor) based N application
N_3: LCC based N application
N_4: No Nitrogen

Table 4. Interaction effect of precision water and nitrogen management on mean grain yield (kg ha^{-1}) of aerobic rice during r*abi* (mean of 2020 and 2021)

Treatments			Nitrogen management		
Irrigation management	N_1	N_2	N_3	N_4	Mean
I_1	3834	3436	3739	2430	3360
I_2	4077	3933	4346	2595	3738
I_3	4467	4813	4604	2799	4171
Mean	4126	4061	4230	2608	
	I	N		I at same N	N at same I
SEm+	144	182		178	207
CD at p-0.05	566	630		648	699

I_1: DRIP irrigation 1.5 Epan in Flat bed system
I_2: DRIP irrigation 1.5 Epan in Raised bed system
I_3: Surface irrigation **(**up to saturation)

N_1: Recommended practice (RDF)- (120:60:40 N P K kg ha^{-1})
N_2: Green seeker (Optical sensor) based N application
N_3: LCC based N application
N_4: No Nitrogen

irrigation (upto saturation) with LCC based N application (4604 kg ha^{-1}) and $_s$urface irrigation with recommended practice of N application (RDF) (4467 kg ha^{-1}). While lowest mean grain yield was recorded with DRIP irrigation in Flat bed system with No Nitrogen application (2430 kg ha^{-1}). Highest grain yield recorded in combination of I_3N_2 might be due to favourable vegetative growth and development as it received sufficient moisture and nitrogen fertilizer at proper amount and critical stages during entire period of growth which helped the crop to improve performance. The higher yield in raised beds under drip irrigation may be the resultant of higher nutrient uptake (Rekha *et al.*, 2015) wherein soil moisture was held at field capacity due to uninterrupted and continuous moisture supply meeting the crop requirement timely (Nagaraju *et al.*, 2017). These results are supported by the findings of (Dinesh *et al.*, 2021). Similarly, LCC and Greenseeker based nitrogen application had resulted in higher grain yields due to increased nitrogen fertilization up to panicle initiation stage,that synchronized with the crop demand under precise application that contributed to higher uptake of nitrogen resulting in better vegetative growth and yield. Similar results were also reported by Bhatta *et al.* (2022) and Baral *et al.* (2021).

Similar trend as observed under grain yield was also observed with straw yield (Table 2) where highest straw yield was recorded with I_3 treatment {Surface irrigation (up to saturation)} (4791 kg ha^{-1}) which differed significantly with I_1 treatment (DRIP irrigation 1.5 Epan in Flat bed system) (4005 kg ha^{-1}). Higher straw yield under surface irrigation can be attributed to more available soil moisture which encouraged higher dry matter production accumulation due to higher photosynthetic activity resulting in production of more photosynthates leading to better growth parameters. Similar findings were recorded with Shahane and Shivay (2021) and Juhi *et al.* (2021). Under nitrogen management practices, LCC based N application produced highest straw yield (4885 kg ha^{-1}) and significantly lowest straw yield was registered with No Nitrogen (3014 kg ha^{-1}). Higher straw yield with LCC based nitrogen management over other treatments could be attributed to immediate supply of nitrogen had a favourable effect on vegetative growth *i.e.*, higher plant height, number of tillers and dry matter production. The findings are in tune with Hemalatha *et al.* (2020).

CONCLUSION

Results of the study showed that continuous submergence is not an obligation in rice cultivation, instead raised beds with drip irrigation is a viable option to yield almost onpar growth parameters and yield of aerobic rice. Use of precision nitrogen management tools such as, LCC and greenseeker under aerobic rice helped in real time N management recording higher growth and yield. This study demonstrated that judicious use of water and N management in real time significantly enhances the crop growth and yield. It may be concluded that the adoption of drip irrigation and N application with LCC were the optimum and best methods of water and N management for aerobic rice.

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Research Article
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EVALUATION OF RICE GENOTYPES FOR SEED VIGOUR AND ASSOCIATED TRAITS

P. MOUNIKA[1], K. JHANSI RANI[2], P. SENGUTTUVEL[3], P. SUJATHA[1] and D. SANJEEVA RAO[3]

[1]Seed Science and Technology, College of Agriculture, Rajendranagar

[2]Agricultural College, Polasa, Jagtial, PJTSAU, Hyderabad

[3]ICAR - Indian Institute of Rice Research, Rajendranagar, Hyderabad

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ABSTRACT

The study was conducted to investigate the variation in seed vigour for seven rice genotypes. The experiment was conducted at Department of Seed Science and Technology, PJTSAU using Completely Randomized Design with three replications during the year 2020-2021. For all the genotypes, data pertaining to seed quality parameters were recorded. Highest seed germination (94 %), dry weight (11.77 mg), seedling vigour index II (1770) and field emergence (91 %) were recorded in Moroberekan. Highest seedling length (28.90 cm), seedling vigour index I (2553), electrical conductivity (14.94 μS/cm/g) were recorded in AUS 276. Highest speed of germination (13.04) and alpha amylase activity (428.50 mg/g) were recorded in IR 64. Lowest seed germination (84 %), seedling length (20.96 cm), seedling vigour index I (1770) and field emergence (83 %) were recorded in N-22. Lowest dry weight, seedling vigour index II, speed of germination, alpha amylase activity and electrical conductivity were recorded in RNR 15048 (4.60 mg, 391 mg), AUS (9.38, 255.95 mg/g) and Dular (6.78 μS/cm/g) respectively. The results indicate that among all the genotypes, Moroberekan recorded highest vigour, Vandana and IR 64 have medium vigour and N-22 and AUS 276 have lower vigour compared to other genotypes. High vigour contributes to their performance in early seedling vigour in field conditions especially in direct seeded conditions. Planting low vigour seeds causes reduced plant height, delayed panicle exsertion and anthesis, less tillering capacity and reduced yield which can be avoided by selecting genotypes with high seed vigour.

Key words: Seed vigour, Germination, Seedling vigour indices, Speed of germination and Alpha amylase.

Rice (*Oryza sativa* L.) is the staple food for almost half of the world's population. In the year 2017 global rice production was 759.6 million metric tons out of which nearly 50% is from China and India (FAO, 2018). The world population is expected to be around 9 billion by 2050. It is crucial to increase rice production further to meet the food demand of the growing population. However, changing climate and decreasing natural resources have become serious threat to enhancing global rice productivity. In global rice productivity, irrigated rice ecosystem comprises 55% of the world's rice-growing area with 75% of world-wide rice production (Naresh *et al.,* 2011). Increasing demand for freshwater availability, severe labour shortage, increasing input prices and global climate change have necessitated a major shift in rice cultivation from lowland transplanted condition to the direct seeded system (Dada *et al.,* 2018 and Sultana *et al.,* 2019). Dry direct seeded rice has many advantages over lowland cultivation. It is less labour intensive, efficient in utilization of water, suitable for upland areas and reduces methane emission (Chauhan *et al.,* 2012). Maintenance of optimum plant population especially during the initial stages of the crop is the major challenge in dry direct sown rice cultivation. Early emergence, good germination percentage and high seedling vigour index are among the desirable traits for dry direct sown rice cultivars.

Weed competition and moisture are the important problems under dry direct seeded rice in the early stages of the crop growth. Hence high seedling vigour is a desirable trait for the genotypes to suit this situation. Early vigour of a genotype is a combination of the ability of the seed to uniformly germinate and emerge after sowing and the ability of the young plant to grow and develop after emergence. Improving crop early vigour is recognized as an effective strategy against the constraints in dry direct seeded rice cultivars (Zhang *et al*., 2005 and Okami *et al.,* 2015). Further, Mahender *et al.* (2015) also reported that rapid uniform germination and accumulation of biomass during initial phase of seedling establishment is an essential phenotypic trait considered as early seedling vigour for direct seeded situation in rice irrespective of environment.

Email: mounikapolagani11@gmail.com

Thus, the present study was conducted on screening of rice genotypes to identify the genotypes with early vigour.

MATERIAL AND METHODS

The experimental material consisted of seven genotypes *viz*., AUS 276, Dular, IR 64, Nagin 22, RNR 15048, Vandana and Moroberekan which were procured from IIRR and ARI, PJTSAU, Rajendranagar, Hyderabad. Dular and N-22 were heat tolerant lines, IR 64 was heat susceptible line, Vandana, AUS 276, Moroberekan were reported to have abiotic stress tolerance and RNR 15048 was high yielding popular variety of PJTSAU. The experiment was carried out in at the Department of Seed Science and Technology, PJTSAU, Rajendranagar using Completely Randomized Design with three replications using the methods given by Panse and Sukhatme (1967). The seed procured was evaluated for initial seed vigour by recording germination percentage, seedling vigour indices, speed of germination, field emergence, alpha amylase activity and electrical conductivity.

Seed Germination (%)

The laboratory test for germination was conducted as per the ISTA rules (ISTA, 2019) by adopting between paper method (BP). Three replications of 100 seeds each in a treatment were used for the germination test that were placed in seed germinator and maintained at constant temperature of 25 ± 2^{0}C and high humidity. On the day of final count *i.e.*, 14th day, the number of seeds germinated was counted and the per cent germination was calculated as follows:

$$\text{Seed Germination (\%)} = \frac{\text{Number of normal seedlings}}{\text{Total number of seeds planted}} \times 100$$

Seedling length (cm) and dry weight (mg)

Ten normal seedlings in each treatment were randomly selected from the germination test for measuring the seedling length in centimetres on 14th day of germination test. These seedlings were then placed in butter paper bags after removing seeds from each seedling. These were placed in hot air oven maintained at 80 ± 1^{0}C for 24 h. After completion of drying period, these seedlings were cooled to room temperature and weight of each seedling was recorded in milligrams per seedling.

Seedling vigour index É and ÉÉ

The seedling vigour indices were calculated as per the method suggested by Abul-Baki and Anderson (1973) as given below and expressed in whole number: -

Seedling vigour index É = Germination (%) × Seedling length (cm)

Seedling vigour index ÉÉ = Germination (%) × Seedling dry weight (mg)

Speed of germination

Germination test was conducted in four replications of 100 seeds each by adopting sand method, in which sand is filled in trays and seeds are sown. Daily germination counts were recorded until no further germination was observed for fourteen days. An index of speed of germination was calculated by adding the quotients of the daily counts divided by the number of days of germination (Maguire, 1962).

$$\text{Speed of germination} = n_1/d_1 + \ldots\ldots + n_{14}/d_{14}$$

Where, n = number of seed germinated on particular day

d = number of days from sowing

Field emergence (%)

Field emergence potential of seeds was measured as per the method suggested by Shenoy *et al.* (1990). Four hundred seeds were sown in four replications of hundred seeds each on raised bed with a spacing of 10 cm between the rows. The number of seeds germinated in each row was recorded on 14th day and percentage field emergence was calculated using the following formula:

$$\text{Field emergence (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds sown}} \times 100$$

Alpha amylase activity (mg/g)

Alpha amylase activity was measured using a colorimetric method with 3,5-dinitrosalicylic acid reagent. In this method, á-amylase breaks down starch into maltose. Maltose released from starch is measured by the reduction of 3,5- dinitrosalicylic acid. The procedure followed as per Sadasivam and Manickam (1991) is detailed below:

The seed was pre germinated for 3 days in petri-plates and 500 mg of pre germinated seed was ground to fine powder using a mortar and pestle. To this powder, 1.8 ml of 0.02 M sodium phosphate buffer (p^H = 6) was added and mixed well. The liquid was transferred into 2 ml eppendorf tube and centrifuged at 20,000 rpm for 20 min. Then 1 ml of the supernatant was transferred into glass test tube using a pipette and 1 ml 0.067 % starch solution was added to it. The tubes were incubated for 15 min at 27^0 C and the reaction was stopped by adding 2 ml 3,5-dinitrosalicylic acid to the solution. The glass tubes were heated in boiling water for 5 min in a water bath. After removing the glass tubes from water bath, 1 ml Rochelle salt was added while the tubes were warm. Then the glass tubes were cooled under running tap water. The volume of the tubes was made to 10 ml by adding 5 ml distilled water and absorbance of the solution was measured at 560 nm using UV-Spectrophotometer. Then standard graph with 0-100 μg maltose was prepared to calculate the concentration of á-amylase.

Electrical conductivity (μS $cm^{-1}g^{-1}$)

Electrical conductivity was measured by following the procedure mentioned in Seed Testing Rules of ISTA, 2019. Three replicates of 50 seeds each drawn randomly from pure seed fraction was weighed to two decimal places. Cleaned conical flasks were used to not affect the conductivity of the samples. We have added 250 ml of distilled water with conductivity of water less than 5 μS cm^{-1} to the containers and covered them with aluminium foils to avoid contamination. The containers were placed at 20 ± 2^0 C for 18-24 h prior to placing the seeds in the water. Two containers were filled with only distilled water used as control. The seed samples were weighed and placed into the prepared containers and swirled gently to completely immerse all the seeds. Each container was covered and placed at 20 ± 2^0 C for 24 h in an incubator. After 24 h, the containers were swirled gently to mix the leachates and the conductivity was measured using a conductivity meter. Conductivity of the samples was calculated by the following formula:

$$\text{Electrical conductivity } (\mu S\ cm^{-1}g^{-1}) = \frac{\text{Conductivity reading } (\mu S\ cm^{-1}) - \text{Background reading}}{\text{Weight of replicate (g)}}$$

RESULTS AND DISCUSSION

The seed procured was assessed for initial seed vigour by recording seed germination percentage, seedling length, dry weight, seedling vigour indices, speed of germination, field emergence, alpha amylase activity and electrical conductivity. The treatment mean sum of squares of genotypes showed significant differences for all parameters except field emergence, suggesting the presence of high variability among genotypes. The variability helps in identifying genotypes with high vigour which can be further used in breeding programmes for development of cultivars suitable for dry direct seeded rice cultivation.

Among the genotypes, significant variation was observed for seed germination but there was no significant variation for field emergence. Among the genotypes, significantly high germination percent was recorded by Moroberekan (94 %) which was on par with Vandana (91 %). Significantly low germination percent was recorded by N-22 (84 %) which was on par with RNR 15048 (85 %), Dular, IR 64 (86 %) and AUS 276 (88 %). The value of field emergence was highest in Moroberekan (91 %) and lowest in N-22 and Vandana (83 %) (Figure 1).

Significant variation was observed for seedling length and seedling vigour index I among the genotypes. Significantly higher seedling length was observed in AUS 276 (28.90 cm) which was on par with Vandana (27.97 cm) and IR 64 (26.50 cm). Significantly lower seedling length was recorded in N-22 (20.96 cm) which was on par with RNR 15048 (22.35 cm) and Dular (22.67 cm). Significantly higher seedling vigour index I was observed in AUS 276 (2553) which was on par with Moroberekan (2374) and Vandana (2546). Significantly lower value was observed in N-22 (1770) which was on par with RNR 15048 (1896) and Dular (1958) (Figure 2 and 3). Tejaswi (2012) and Anusha *et al.* (2020) also reported that seedling length which represents rapid cell elongation is an important parameter for seedling vigour index.

Table 1. Mean values for seed quality parameters of rice genotypes

Genotypes	Seed germination (%)	Seedling length (cm)	Dry weight (mg)	Seedling vigour index I	Seedling vigour index II	Speed of germination	Field emergence (%)	Electrical conductivity (μS/cm/g)	Alpha Amylase activity (mg/g)
AUS 276	88^{bc}	28.90^{a}	9.90^{b}	2553^{a}	874^{bc}	9.38^{f}	86^{a}	14.94^{a}	255.95^{f}
Dular	86^{bc}	22.67^{de}	7.57^{e}	1958^{e}	652^{e}	11.13^{bcd}	85^{a}	6.78^{f}	413.89^{ab}
IR 64	86^{bc}	26.50^{abc}	9.87^{bc}	2285^{cd}	851^{bcd}	13.04^{a}	85^{a}	9.41^{cd}	428.50^{a}
N-22	84^{c}	20.96^{e}	7.23^{ef}	1770^{e}	611^{ef}	10.09^{cdef}	83^{a}	9.51^{c}	307.65^{cd}
RNR 15048	85^{c}	22.35^{e}	4.60^{g}	1896^{e}	391^{g}	10.99^{bcde}	85^{a}	11.16^{b}	305.91^{cde}
Vandana	91^{ab}	27.97^{ab}	9.80^{bcd}	2546^{ab}	892^{b}	12.40^{ab}	83^{a}	8.60^{cde}	267.61^{def}
Moroberekan	94^{a}	25.23^{cd}	11.77^{a}	2372^{abc}	1107^{a}	11.65^{abc}	91^{a}	6.86^{f}	347.19^{c}
Grand mean	88	24.94	8.68	2197	768	11.24	85	9.61	332.39
SEm (±)	1.737	0.842	0.308	80.874	30.480	0.520	2.545	0.427	15.314
CD (P=0.05)	5.268	2.553	0.935	245.306	92.453	1.578	7.719	1.295	46.451
C.V (%)	3.422	5.845	6.151	6.375	6.872	8.020	5.157	7.695	7.980

*Similar alphabets attached to the numericals are on par.

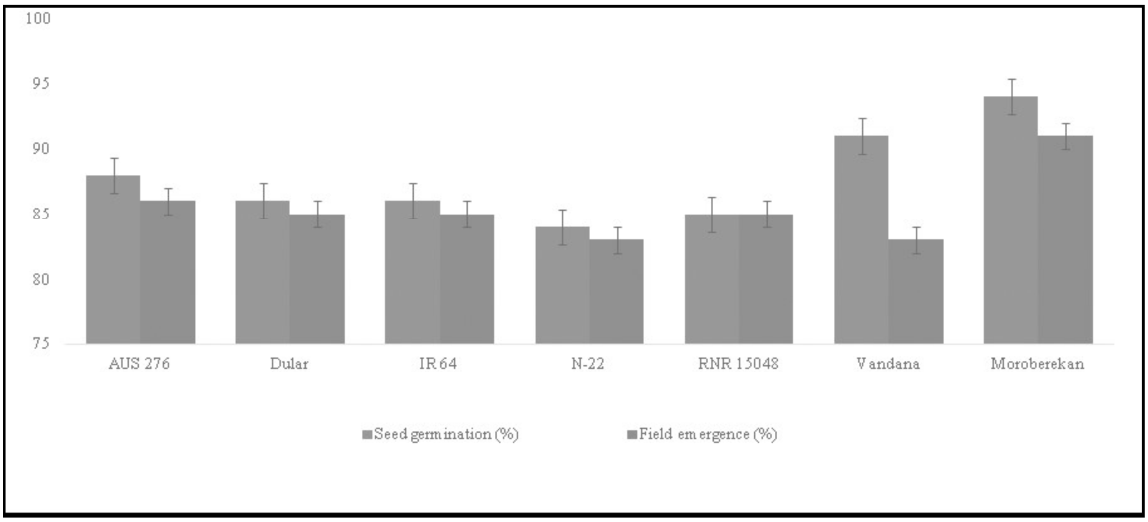

Figure 1. Comparison of seed germination and field emergence for the seven rice genotypes

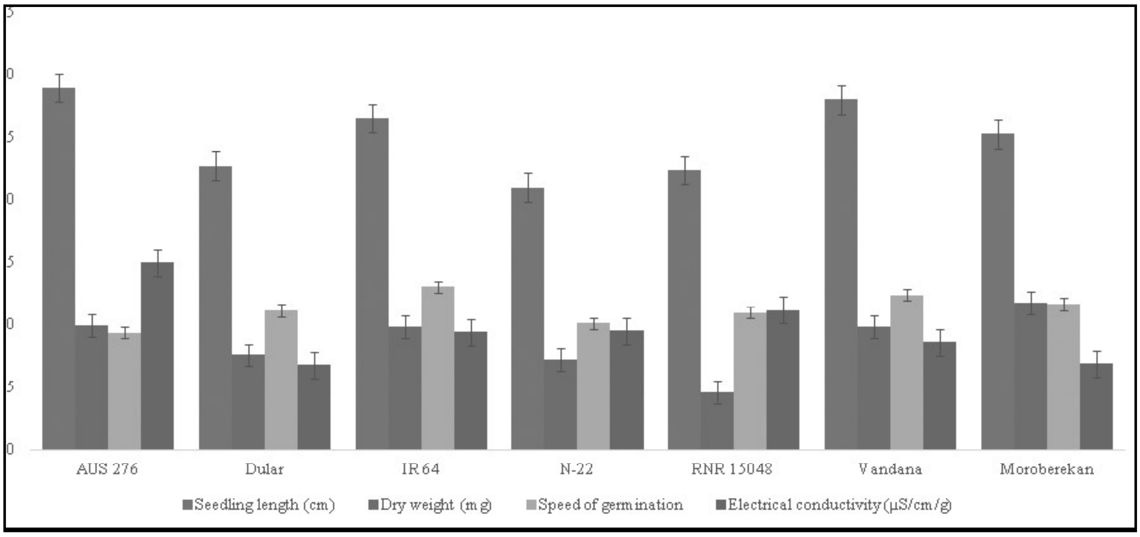

Figure 2. Comparison of seedling length, dry weight, speed of germination and electrical conductivity for the seven rice genotypes

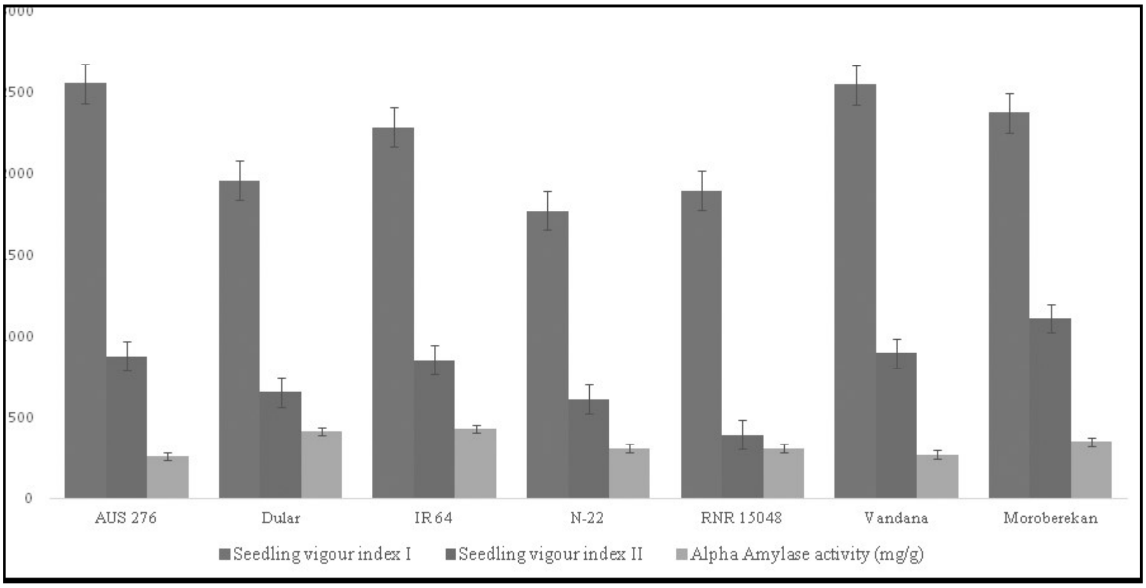

Figure 3. Comparison of seedling vigour indices and alpha amylase activity for the seven rice genotypes

Significant variation was observed for seedling dry weight and seedling vigour index II among the genotypes. Significantly high dry weight was recorded in Moroberekan (11.77 mg), whereas significantly lower dry weight was recorded in RNR 15048 (4.60 mg). Dry weights of Vandana (9.80 mg), IR 64 (9.87 mg) and ASU 276 (9.90 mg) were on par with each other. Significantly higher seedling vigour index II was observed in Moroberekan (1107), whereas significantly lower value was observed in RNR 15048 (391). The seedling vigour index II of IR 64 (851), AUS 276 (874) and Vandana (892) were on par with each other (Figure 2 and 3).

Speed of germination determines the earliness of emergence of a particular genotype at seedling stage. Significantly higher speed of germination was recorded in IR 64 (13.04) which was on par with Moroberekan (11.65) and Vandana (12.40). Significantly lower speed of germination was recorded in AUS 276 (9.38) which was on par with N-22 (10.09) (Figure 2).

Electrical conductivity indicates the amount of leachates released from the seed due to seed deterioration. The higher the amount of leachates the lower is the vigour of the seed lot. Significantly lower electrical conductivity was observed in Dular (6.78 μS/cm/g) which was on par with Moroberekan (6.86 μS/cm/g). Significantly higher electrical conductivity was recorded in AUS 276 (14.94 μS/cm/g). The genotypes with lower values of electrical conductivity were considered to have high vigour (Figure 2).

Alpha amylase is an important enzyme that helps in the breakdown of starch present in the seed endosperm to provide nutrients for the radicle emergence after imbibition. The higher is the enzyme activity the faster is the emergence of the radicle which in turn results in faster seedling emergence. Significantly high alpha amylase activity was recorded in IR 64 (428.50 mg/g) which was on par with Dular (413.5 mg/g). Significantly lower value was recorded in AUS 276 (255.95 mg/g) which was on par with Vandana (267.61 mg/g). Similar results were observed by Anusha *et al.* (2020) suggesting that alpha amylase can be used as a biochemical marker for screening of rice genotypes for early seedling vigour (Table 1 and Figure 3).

CONCLUSION

The results indicate that among all the genotypes, Moroberekan recorded highest seedling vigour, Vandana and IR 64 have medium vigour and N-22, RNR 15048 and AUS 276 have lower vigour compared to other genotypes. Germination percentage of the seeds was observed to be high in all the genotypes. However, mere germination is not sufficient for dry direct seeded rice. It requires rapid seedling growth after emergence. Based on all the vigour parameters recorded, better genotypes can be identified that might be suitable to direct seeded rice conditions.

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Research Article
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DELINEATION OF NUTRIENT MANAGEMENT ZONES IN MAIZE TRACTS OF TELANGANA USING MAXIMUM CURVATURE METHOD

V. B. PANDIT[1], T. ANJAIAH[2], M. UMA DEVI[3], T. L. NEELIMA[4] and D. SRINIVASA CHARY[5]

[1]Department of Soil Science and Agricultural Chemistry, PJTSAU, Rajendranagar, Hyderabad,

[2]AICRP on Micronutrients, Secondary and Pollutant elements, ARI, PJTSAU, Rajendranagar, Hyderabad

[3]Department of Soil Science and Agricultural Chemistry, Jagtial, PJTSAU, Telangana

[4]Water Technology Centre, PJTSAU, Rajendranagar, Hyderabad

[5]Department of Statistics and Mathematics, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad

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ABSTRACT

To maximize financial gain, minimize environmental impact, and improve soil and crop management, soil fertility must be maintained uniformly. Delineation of management zones (MZs) is the one option to divide soil variability in to different soil fertility classes. MZs with uniform production potential might offer a useful strategy for nutrient application. The present study was conducted in the Molligipalem village of Karimnagar district, Northern Telangana zone during 2020 to delineate management zones in maize for N, P and K. One hundred of surfaces georeferenced soil samples were collected and analyzed for pH, EC, SOC, available N, P, K, Fe, Mn, Zn and Cu. Soil properties variations were discussed with descriptive statistics and delineation of management zones was done with maximum curvature method. The descriptive statistics revealed that soil is neutral to slightly alkaline in reaction, with the lowest variability. The SOC content and available N was low in soil having less than 20 % variation. Available P and K was medium to high in soil with 20-30 % variation. The available micronutrient status (Fe, Mn, Zn and Cu) in the soil was sufficient with 58 to 75 % variation. Maximum curvature method was found to show wide variation in soil properties and the unit used for distance in m^2. In present study, the size of homogeneous zone for pH, EC, SOC, available N, P_2O_5, K_2O, Fe, Mn, Zn and Cu were 3200 m^2, 1600 m^2, 2400 m^2, 1600 m^2,1600 m^2,2000 m^2, 3200 m^2, 2400 m^2, 4800 m^2 and 3600 m^2 respectively. As micronutrient content was sufficient in the soil, hence it is not considered delineation of soil management zone. For site specific nutrient management, three soil management zone was estimated using N, P, and K data.

Key words: Coefficient of variation, management zone and maximum curvature

Telangana is a semi-arid area and has a predominantly hot and dry climate. The Central Deccan Plateau's dry deciduous forests ecoregion covers much of the state. The annual rainfall is ranged from 900 to 1500 mm in Northern Telangana and received from the southwest monsoons. Various types of soils in Telangana is the result of a complex interaction between geology, topography, climate, and vegetation. Parent material, topography, and climate influence soil attribute such as texture, type of clay, amount of clay, CEC, pH, EC, soil fertility status, *etc*. The occurrence of Spatial variability in soil attributes is also caused by the parent material, terrains, climate, and other soil management factors such as fertilizer application and irrigation. Due to land degradation, the long-term viability of many current cropping methods in dry regions is in doubt. Due to their naturally low quantities of organic matter, soils are typically underdeveloped and vulnerable to structural deterioration. The fertilizer use efficiency in these regions' crops is often less than 25% and quite variable (Singh *et al.* 2007). Inputs like fertilizers have typically minimal effects on crops, making them unprofitable for farmers. Strategic fertilizer use could increase the effectiveness and result in significant increases in crop yield and biomass production. Due to the substantial spatial heterogeneity of nutrients within particular fields, application rates should ideally be adjusted based on estimates of the needs for optimal production at each location (Page *et al.,* 2005; Rufo *et al.,* 2005). Therefore, effective methods should be used to precisely measure changes in soil parameters within a field and to define homogeneous management zones (MZs) for the balanced application of fertilizers (Peralta and Costa, 2013). Within the area defined by field boundaries, the MZ idea encourages the identification of regions (management zones). These subfield regions are parts of a field that share features like topography, texture, and nutrient content. However, due to the intricate interactions of all the elements that could affect crop productivity, it is challenging to establish management zones with accuracy. Determining management by sub-fields can also be highly challenging since components interact dynamically. Within agricultural fields, the soil

Email: vaibhavphotos1995@gmail.com

characteristics that limit crop productivity frequently fluctuate greatly across both time and location. Usually, this variability is deliberately ignored in soil sample strategies, laboratory testing, and agronomic crop management techniques. In light of this, it would seem that implementing solutions for soil-specific conditions within the context of precision agriculture would have the potential to enhance the way in which soils are currently handled. The ability of contemporary technologies to take exact measurements has made it easier to quantify the spatial variation of soil and terrain elements. For defining management zones, a number of conventional methods have been utilized, including soil surveys and topographical maps (Reyniers *et al.,* 2006), the crop yield-based management zone methodology (Flowers *et al.,* 2005; Hornung *et al.,* 2006), and the nutrient index technique (Jena *et al.,* 2015). Maximum curvature method is one of the methods used for soil management zone delineation. In Maximum curvature method, Coefficient of variation (CV) is used to sort variation in the field. A high coefficient of variation suggests a significant variation in the soil fertility, whereas a low coefficient of variation indicates a little variation in the soil fertility. Coefficient of variation is directly proportional to the variance in soil fertility. In view of the above facts, the present study was done to identify soil management zone for site specific nutrient management in maize using maximum curvature method.

MATERIAL AND METHODS

Study area

This study was conducted in the Mall Reddy farm**,** Mogilipalem villages located in the Karimnagar districts of Telangana, India. The total cultivated area of the farm was 4 ha which is intensively cultivated.

Soil sampling and analysis

one hundred surface soil sample was collected from each grid (grid size is 20 *20 m) using a GPS unit during 2020. Soil samples were kept in plastic bottles for soil analysis after air drying, thorough mixing, gentle grinding in a wooden mortar, and finally passing through a 2-mm sieve. Electrical conductivity (EC) and pH of the soil were measured in 1:2.5 soil solution (Jackson, 1973). The Walkley and Black (1934) method was used to estimate soil organic carbon (SOC) content. The alkaline permanganate method, as described by Subbiah and Asija (1956), was used to determine the available N (AN) concentration. According to Olsen *et al.* (1954) available P (AP) was extracted using 0.5 M sodium bicarbonate (pH 8.5). Available potassium (AK) was extracted using neutral 1N ammonium acetate and measured using a flame photometer (Hanway and Heidel 1952). The process described by Lindsay and Norvell (1978) was used to extract the readily available micronutrients, Zn, Cu, Fe, and Mn, using diethylene triamine pentacetic acid (DTPA).

Statistical analysis

Descriptive analysis

For observing the data variability, the central tendency and dispersion of numerous soil characteristics were determined, included minimum, maximum, mean, standard deviation, coefficient of variation, median, interquartile range, skewness, and kurtosis. The descriptive statistics for soil parameters were calculated in Microsoft excel.

Maximum curvature method

To select the optimal plot size, the coefficient of variability per unit area is considered as an indicator. This process involves plotting a CV (coefficient of variation per unit area) vs. plot size curve. As a result, the CV per cent per unit area was calculated for various plot sizes (*i.e.* 1, 2,...) using the formula below.

$$\text{CV (\%)} = \left(\frac{\text{Standard deviation}}{\text{Mean}}\right)$$

In this method the basic units of uniformity trails are combined to form new units. The new units are formed by combining columns, rows or both. Combination of columns and rows should be done in such a way that no column or row is left out. For each set of units, the coefficient of variation (C.V) is computed. A curve is plotted by taking the plot size (in terms of basic units) on the X-axis and the C.V. values on the Y-axis of a graph sheet. The point at which the curve taken a turn, that is, the point of maximum curvature is located by inspection. The value corresponding to the point of maximum curvature will be the optimum plot size. (Sundarraj, 1977).

This is only an approximate method of fixing the optimum plot size. We may the use calculus method to find out the exact optimum plot size as explained below.

$$y = a/x^b$$

$$\text{or} \quad \log y = \log a - b \log x$$

When more than one C.V. is there for the same plot size, the minimum C. V .is taken for fitting the curve.

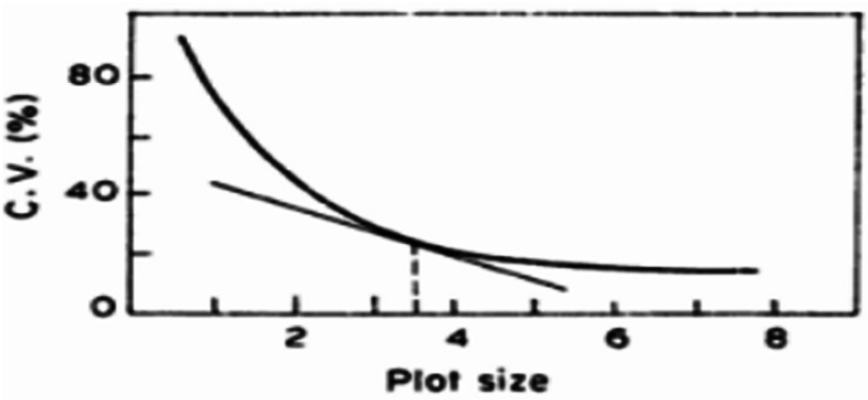


Table 1. Field layout for combination of row and column (plot size – 400 m²)

R/C	C1	C2	C3	C4	C5	C6	C7	C8
R1								
R2								
R3								
R4								
R5								
R6								
R7								
R8								
R9								
R10								
R11								

RESULTS AND DISCUSSION

Descriptive statistics of soil properties

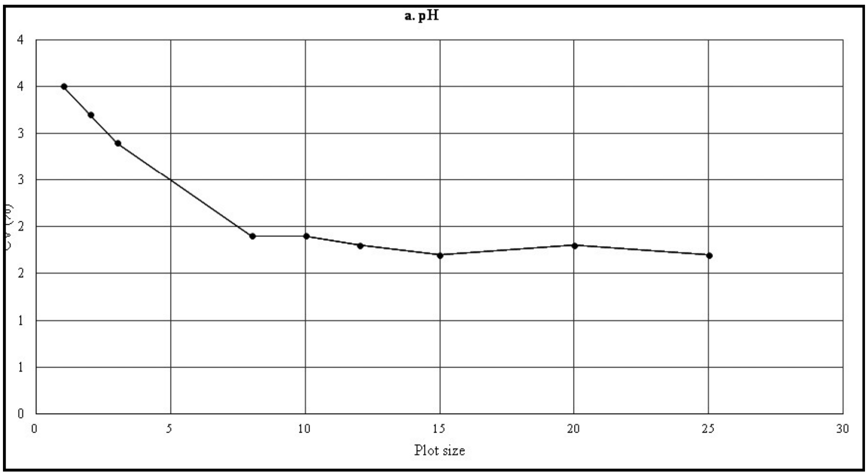
Descriptive statistics for the soil variables are presented in Table 3 revealed that the pH ranged from 6.88 to 7.89 indicates a neutral to slightly alkaline in reaction having the lowest coefficient of variation (3.51 %). Other investigations have also found that the pH of soil varies less than other soil characteristics (Reza *et al.,* 2017; Shukla *et al.,* 2017). The fact that pH values are a log scale of proton concentration in soil solution accounts for the low variability of pH. In general, the soil buffering capacity in the studied area resists the abrupt change in soil pH or its significant fluctuation under various cropping systems. Except for SOC, available N, and available K_2O, the remaining soil characteristics showed moderate (CV 25–75%) variability. Soil organic carbon content varied from 0.14 – 0.53 % with a mean value of 0.29 % having a coefficient of variation of 16.92 %. The available nitrogen content in soil was low (ranged between 89 – 163 kg N ha^{-1}) with mean value of 124 kg N ha^{-1} having 14.50 % CV. Low variability in SOC and available N was overserved due to the same cropping system for a long time without FYM application. The same result was found by Silva *et al.* (2009). The average soil available K_2O content was high (312 kg K_2O ha^{-1}) with CV of 21%. Soil available P_2O_5 content was medium to high with an average value of 66 kg P_2O_5 ha^{-1} and varied from 30 to 105 kg P_2O_5 ha^{-1}. Similar to this, research by Camacho-Tamayo *et al.* (2008) found that phosphorus buildup was caused by prior fertilizer application at the Santa Cruz farm in Colombia's eastern lowlands. Soils of the farmer field showed both deficiency and sufficiency in available S within the farm with a mean value of 16 mg kg^{-1} with 52 % CV. Moderate variability of available S was observed which pertained to the guidelines provided by Warrick (1998). Moderate variability of available S in the soil might be due to the mobile and dynamic nature of Sulphur in soil, which is corroborated by Han *et al.* (2005). The mean values of Fe, Mn, Zn and Cu in this region were 37, 12, 4 and 4 mg kg^{-1}, respectively, and their concentrations varied widely. As compared to macronutrients, the micronutrients' CV values were high (58 % for Fe, 67.20 % for Mn, 61. 50 % for Zn and 75 % for Cu) from 58% - 75%. The adoption of various soil management strategies, such as variance in fertilizer application and other crop management activities, may be the cause of this variation of soil attributes in the analyzed locations (Srinivasa rao *et al*., 2014; Shukla *et al*., 2017). Overall, the study area's soil was characterized by significant variability

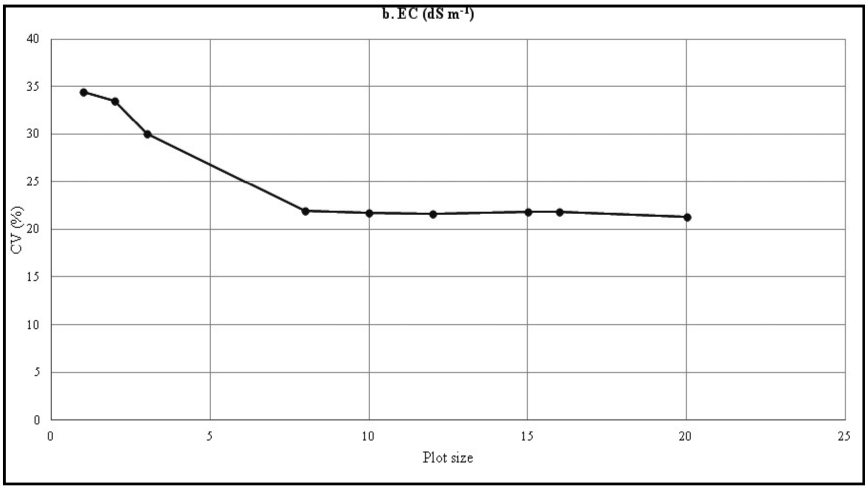
Table 2. Plot Combination, Plot size, and No. of plot formation from 100-unit plot

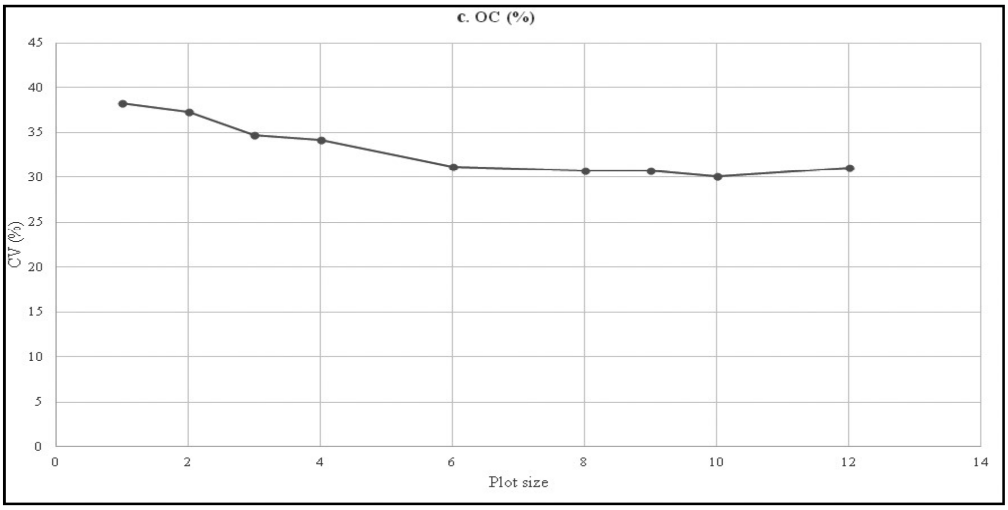
S.No.	Plot combinations (R * C)	Plot size(m^2)	No. of plot	S.No.	Plot Combination (R*C)	Plot size (m^2)	No. of plot
1	1*2	2	50	24	2*7	14	7
2	2*1	2	50	25	7*2	14	7
3	2*2	4	25	26	2*9	14	7
4	1*4	4	25	27	5*3	15	6
5	4*1	4	25	28	3*5	15	6
6	2*3	6	16	29	2*8	16	6
7	3*2	6	16	30	8*2	16	6
8	1*6	6	16	31	2*9	18	5
9	6*1	6	16	32	9*2	18	5
10	2*4	8	12	33	2*10	20	5
11	4*2	8	12	34	10*2	20	5
12	1*8	8	12	35	5*4	20	5
13	8*1	8	12	36	4*5	20	5
14	2*5	10	10	37	7*3	21	4
15	5*2	10	10	38	3*7	21	4
16	1*10	10	10	39	11*2	22	4
17	10*1	10	10	40	4*6	24	4
18	2*6	12	8	41	6*4	24	4
19	6*2	12	8	42	5*5	25	4
20	3*4	12	8				
21	4*3	12	8				
22	1*12	12	8				
23	12*1	12	8				

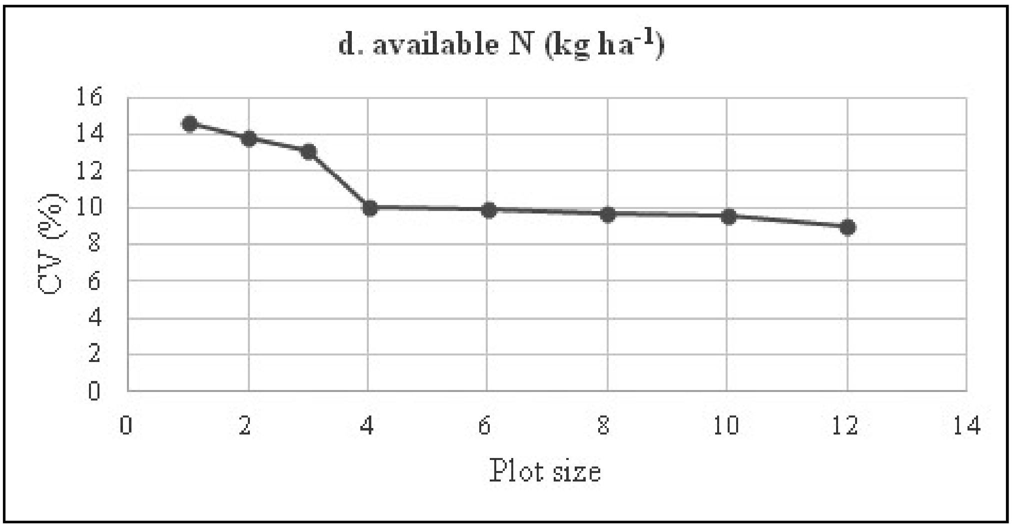
Table 3. Descriptive statistics of soil properties in maize tracts of Karimnagar, Telangana

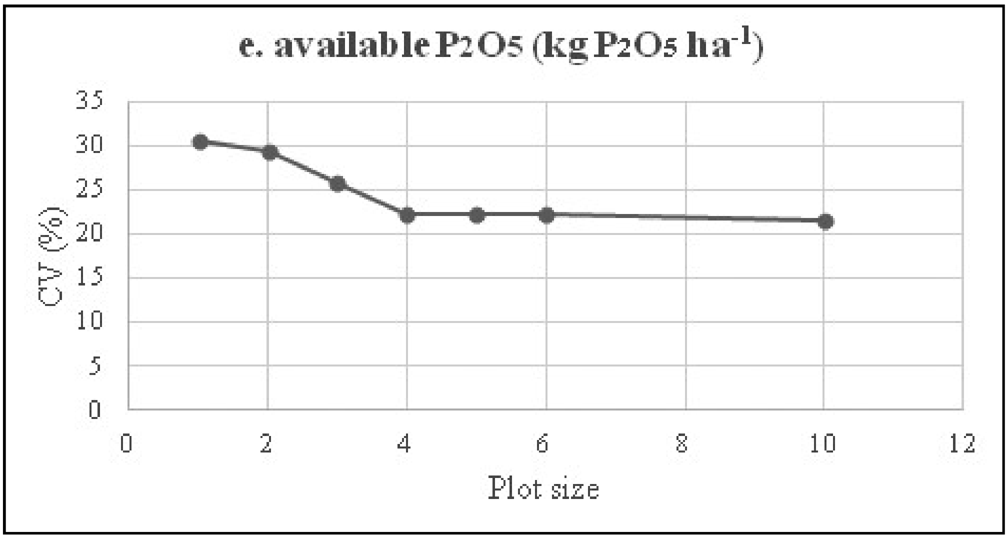
Parameters	Minimum	Maximum	Mean	Range	Kurtosis	Skewness	S.D.	C.V. (%)
pH	6.88	7.89	7.40	1.01	-0.71	-0.06	0.26	3.51
EC	0.09	0.359	0.21	0.26	-1.13	0.15	0.07	33.33
SOC (%)	0.14	0.53	0.29	0.39	-0.79	0.65	0.11	16.92
AN (kg ha^{-1})	89	163	124	74	-0.64	0.02	18.00	14.50
AP_2O_5 (kg ha^{-1})	30	105	66	75	-1.24	0.02	20.00	30.00
AK_2O (kg ha^{-1})	208	444	312	236	-0.83	0.32	66.00	21.00
AS (mg kg^{-1})	4	39	16	35	0.06	0.71	8.31	52.00
Fe (mg kg^{-1})	3	79	37	76	-0.89	0.19	21.40	58.00
Mn (mg kg^{-1})	0.44	26.36	12	26	-1.11	0.29	8.06	67.20
Zn (mg kg^{-1})	0.4	8	4	7	-1.25	0.14	2.46	61.50
Cu (mg kg^{-1})	0.6	11	4	10	-0.25	0.82	3.00	75.00

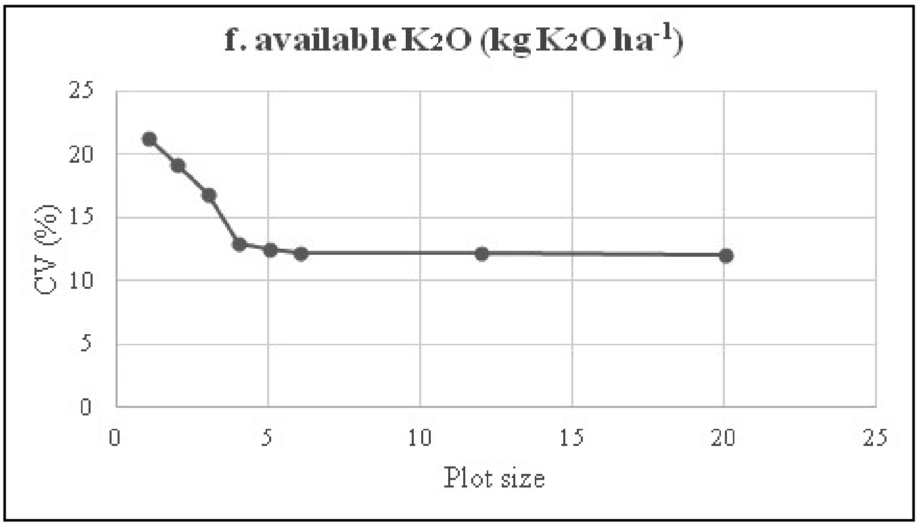


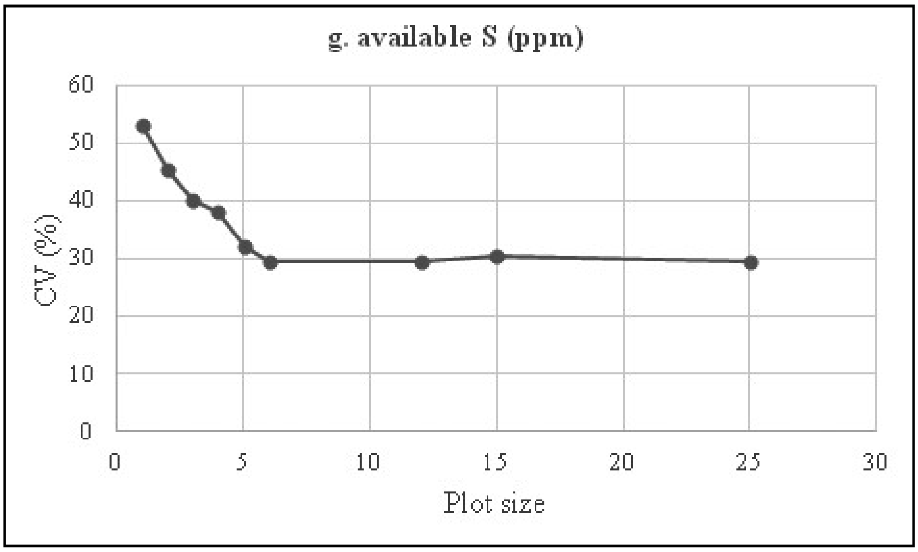


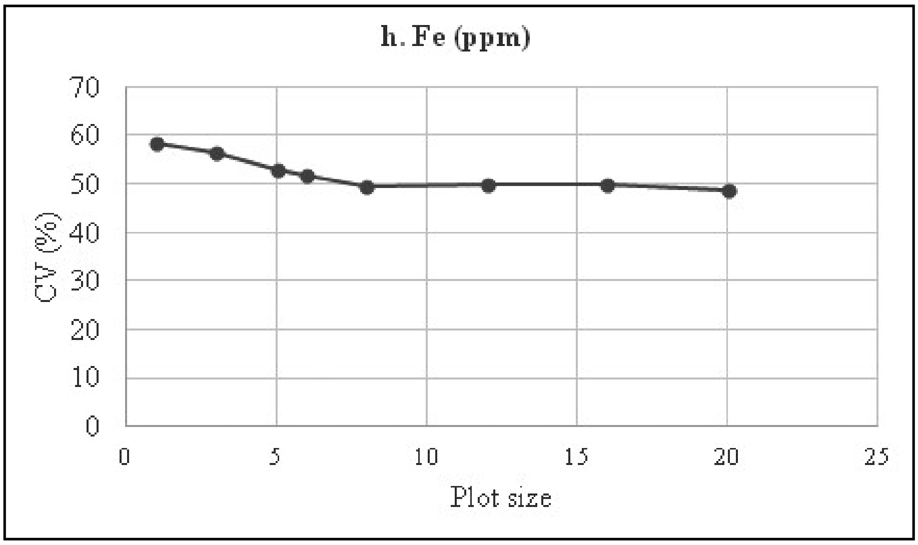

c. OC (%)
CV (%)
Plot size

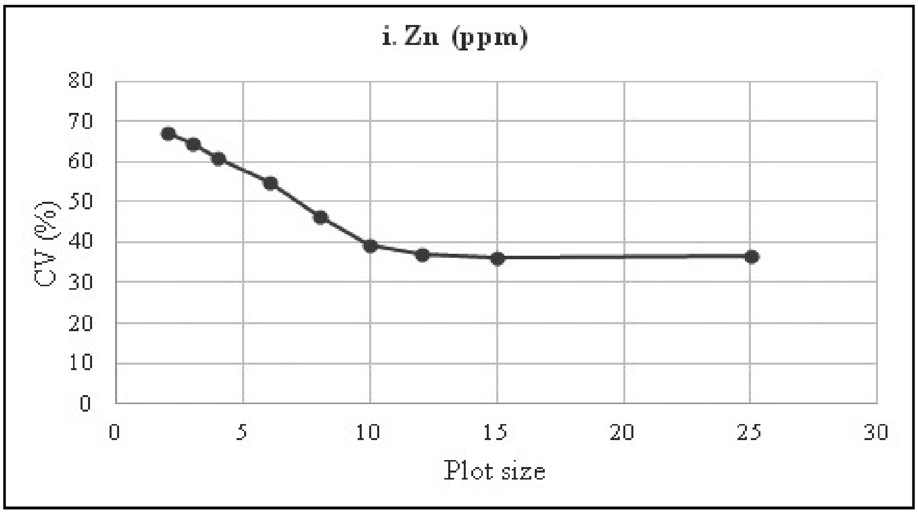

d. available N (kg ha-1)
CV (%)
Plot size

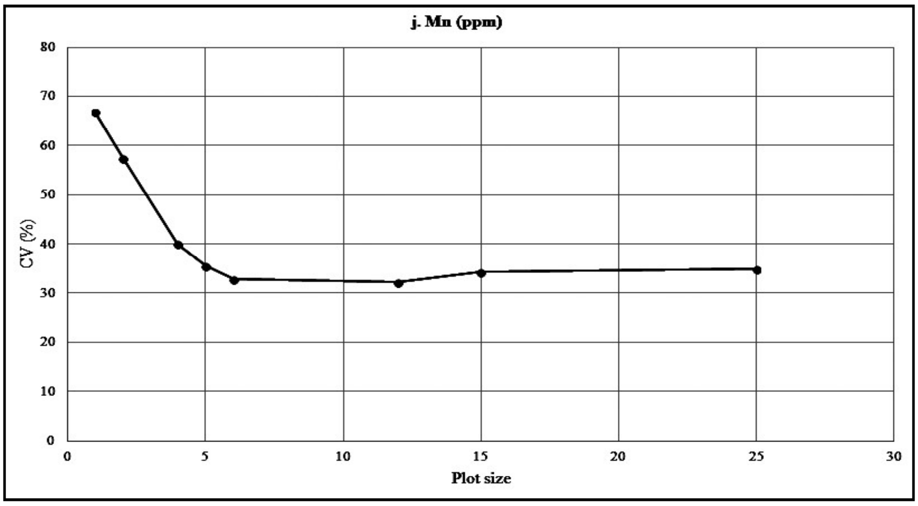

e. available P2O5 (kg P2O5 ha-1)
CV (%)
Plot size


f. available K2O (kg K2O ha-1)
CV (%)
Plot size
0
5
10
15
20
25


g. available S (ppm)
CV (%)
Plot size
0
10
20
30
40
50
60
0
5
10
15
20
25
30


h. Fe (ppm)
CV (%)
Plot size
0
10
20
30
40
50
60
70
0
5
10
15
20
25





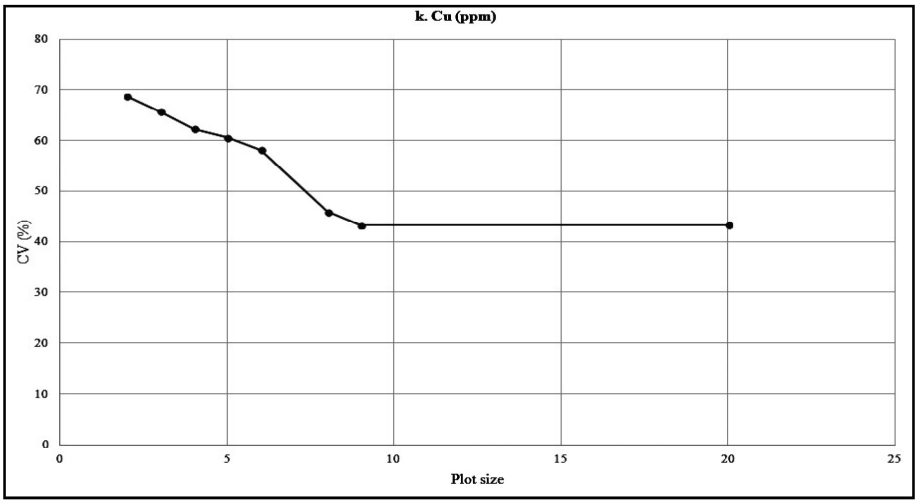


Figure 1. Maximum curvature graph - a - pH, b- EC, c- SOC, d- AN, e-AP_2O_5, f- AK_20, g-AS, h– Fe, i - Mn, j- Zn and k – Cu

Table 4. Coefficient of variation of various plot sizes for soil: a - pH, b- EC, c- SOC, d- AN, e-AP_2O_5, f-AK_20, g-AS, h– Fe, i - Mn, j- Zn and k - Cu

a. Plot size (m^2)	CV (pH) (%)
1	3.5
2	3.2
3	2.9
8	1.9
10	1.9
12	1.8
15	1.7
20	1.8
25	1.7

b. Plot size (m^2)	CV (EC) (%)
1	34.47
2	33.52
3	30.00
8	21.95
10	21.71
12	21.62
15	21.87
16	21.87
20	21.28

c. Plot size (m^2)	CV (OC) (%)
1	38.2
2	37.3
3	34.7
4	34.2
6	31.1
8	30.7
9	30.7
10	30.1
12	31.0

d. Plot size (m^2)	CV (N) (%)
1	14.6
2	13.8
3	13.1
4	10.0
6	9.9
8	9.7
10	9.6
12	9.0

e. Plot size (m^2)	CV (P) (%)
1	30.51
2	29.32
3	25.76
4	22.20
5	22.34
6	22.27
10	21.61

f. Plot size (m^2)	CV (K) (%)
1	21.22
2	19.21
3	16.79
4	12.88
5	12.50
6	12.18
12	12.24
20	12.06

g. Plot size (m^2)	CV (S) (%)
1	53.21
2	45.47
3	40.19
4	37.95
5	32.06
6	29.49
12	29.41
15	30.45
25	29.54

h. Plot size (m^2)	CV (Fe)(%)
1	58.59
3	56.58
5	53.03
6	51.82
8	49.40
12	49.72
16	50.93
20	47.99

i. Plot Size (m^2)	CV (Zn) (%)
2	67.08
3	64.54
4	61.10
6	54.69
8	46.33
10	39.42
12	36.91
15	36.37
25	36.63

j. Plot size (m^2)	CV (Mn) (m^2)
1	66.85
2	57.38
4	40.01
5	35.62
6	32.83
12	32.20
15	34.30
25	34.88

k. Plot size (m^2)	CV (Cu) (%)
2	68.7
3	65.7
4	62.3
5	60.6
6	58.2
8	45.9
9	43.2
20	43.3

and high nutrient levels. When nutrients were applied uniformly, the supply of nutrients varied depending on their composition in the particular site of the study area, which might have led to spatial variability in crop production.

Soil variability by maximum curvature method

Soil variability in the maize field of Karimnagar is presented in Table 5 and Figure1. The plot size was calculated for plotting maximum curvature graph using different row and columns combination is present in Table 1 and 2. The maximum curvature graph for soil parameters were plotted by considering the CV value of plot size, which mentioned in Table 4 (a-k). Table 5 showed that the range of soil variability was between 1600 and 4800 m^2. It indicates that soil properties vary for every 1600 to 4800 m^2 distance. In the maize field of Karimnagar, spatial variability of EC, available N and available P were homogenous up to 1600 m^2 distance. It indicates that spatial heterogeneity of EC, available N, and available P will occur after 1600 m^2. Similarly, the spatial homogeneity of SOC, available S, and Mn was up to 2400 m^2. Spatial uniformity of pH and Fe was observed within 3200 m^2 and the spatial homogenous zone for Cu was near to pH and Fe zone (3600 m^2). The size of the homogenous zone of Zn was 4800 m^2. The size of the homogenous zone for soil properties varied from 1600 to 4800 m^2 due to the intrinsic factors of soil properties and mineralogy, extrinsic factors such as anthropogenic activities, and both intrinsic and extrinsic factors respectively (Cambardella *et al.*, 1994; Liu *et al.,* 2006).

Delineation of nutrient management zones

Soil management zone is important to do site-specific nutrient management of N, P and K based on STCR and Targeted yield approach. Table 5 revealed that there is six management zone or homogenous zones per ha in the maize field of Karimnagar Six management zones were observed per ha in the maximum curvature method based on available N, P, and K data. Optimum homogenous plot sizes of Available N, P_2O_5 and K_2O were 1600 m^2, 1600 m^2 and 2000 m^2 respectively. Among available N, P_2O_5 and K_2O plot sizes, the lowest plot size *i.e.* 1600 m^2 was considered for delineation the management zone which was repeated in six times in one ha. Therefore, six management zone was selected for further field trials. The available micronutrient content in the soil was sufficient, therefore soil micronutrient was not considered in the delineation of management zones for micronutrients.

CONCLUSION

From the above result and discussion, it was concluded that there is wide variability in soil properties. The management zones observed in the maize field using the maximum curvature method were three. These three management zones should be for soil sample collection, analysis and the laboratory result

Table 5. Soil variability analysis in maize field of Karimnagar by maximum curvature method

S.No.	Soil Properties	No. of plot	Distance (m^2)
1	pH	8	3200
2	EC	4	1600
3	OC	6	2400
4	Available N	4	1600
5	Available P_2O_5	4	1600
6	Available K_2O	5	2000
7	Available S	6	2400
8	Available Fe	8	3200
9	Available Mn	6	2400
10	Available Zn	12	4800
11	Available Cu	9	3600

to make N, P, and K fertilizer recommendations based the on STCR model and the Targeted yield approach.

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Research Article
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INFLUENCE OF ESTABLISHMENT METHODS, WATER REGIMES AND INTEGRATED NITROGEN MANAGEMENT ON GROWTH AND YIELD OF *RABI* RICE

D. MADHURYA[1], A. MADHAVI LATA[2], T. L. NEELIMA[3], R. MAHENDER KUMAR[4], A. MADHAVI[5], A. MEENA[6] and M. YAKADRI[7]

[1]Department of Agronomy, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad
[2]Agricultural Polytechnic, Malthummeda, PJTSAU
[3]Department of Agronomy, Water Technology Centre, Rajendranagar, PJTSAU
[4]AICRIP(Agronomy), Crop Production Section, ICAR-Indian Institute Of Rice Research, Hyderabad
[5]AICRP on STCR, ARI, Rajendranagar, Hyderabad
[6]Department of Statistics and Mathematics, College of Agriculture, Rajendranagar, Hyderabad
[7]Department of Agronomy, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad

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ABSTRACT

Traditional rice cultivation with huge water consumption and judicious fertilizer application had a gloomy effect on environment. Rice although being an important staple crop, its cultivation has become difficult in light of climate change. Sustainable strategies for rice cultivation under climate change scenario is gaining importance and factors which improve the economic yield and reduce the inputs has gained much importance. To identify the best sustainable method in rice cultivation, the present study was conducted at College farm, College of Agriculture, Rajendranagar, Professor Jayashankar Telangana State Agricultural University during *rabi* 2020-21 and 2021-22 to study the effect of establishment methods and water management practices on growth and yield of *rabi* rice. The experiment consisted of establishment methods with water management as Vertical plots *viz.* M_1: Normal Transplanting; M_2: Direct seeded rice with drum seeder; M_3: Normal Transplanting with alternate wetting and drying water management at depletion of 5 cm; M_4: Direct seeded rice with alternate wetting and drying water management at depletion of 5 cm, and five nitrogen management practices as Horizontal plots *viz.* N_1:100% RDF; N_2:75% RDN+25% N through biogas slurry; N_3 :75% RDN+25% N through *Azolla* compost ; N_4:75% RDN+25% N through vermicompost; N_5:75% RDN+ 25%N through poultry manure. The results revealed that among the main plots, rice established by direct seeded rice with alternate wetting and drying water management at depletion of 5 cm and application of 75% RDN+ 25%N through poultry manure among the sub treatments performed better over other treatments by recording higher plant height, dry matter accumulation, LAI and no. of tillers per m^2. Significantly higher grain and straw yield of rice was obtained with the combination of direct seeded rice with alternate wetting and drying water management at depletion of 5 cm and 75% RDN+ 25%N through poultry manure.

Key words: Drum seeder, Transplanting, Flooding, AWD and Poultry manure.

Rice is one of the major staple and nutritious crop in the world. India is the second largest producer of rice with a production potential of 178.31 MMT during 2020 (www.statistica.com). Telangana is the rice bowl of South India with 2 M ha of area under rice cultivation during 2020. Rice although being an important staple crop, the traditional lowland irrigated rice cultivation was facing severe problems in light of limited natural resources *viz.,* water and nutrients. Increased water consumption, improper establishing methods, inefficient and inappropriate use of inorganic compounds resulted in reduced rice yields. With the rapid depletion in water resources 20% of our present irrigated field may expect physical water scarcity.(Ishfaq *et al.,* 2021). Conventional system consumes a large amount of water, to tackle this problem efficient water saving methods are required and alternate wetting and drying is one such method to save water and improve yields in rice cultivation. Safe AWD irrigation performed well under low land rice cultivation without reduction in yield (Mote *et al.* 2017, 2019). AWD lowers water use by 35%, improved water productivity by 40% (Sathish *et al.* 2017) and yield by 20% Anning *et al.* (2018). Alternate wetting and drying (AWD) water management and suitable N management are two important practices for sustenance of rice production and their positive interactions on rice yield and N use efficiency determined thorough coordination of the source-sink relationship (Wang *et al.,* 2016).

Search for viable alternatives to traditional rice cultivation is the need of the hour. Wet Direct seeded rice (W-DSR) technology is found to be an alternative

Email: madhuryadakarapu9@gmail.com

which offers saving in labor (40–45%), water (30– 40%) and energy to the extent of 60–70% (Yaduraju *et al.*, 2021). Alternate wetting and drying has been reported to reduce water inputs by 25-70% (Ishfaq *et al.,* 2020), increased grain yields by 12.0–15.4% (Norton *et al.,* 2017) compared to continuously flooded rice systems. Application of organic fertilizers serve as a sustainable alternative to chemical fertilizers and improve the quality of produce. Nitrogen (N) is the key nutrient input that limits rice growth and productivity (Yoshida, 1981). The slow releasing nature of organic manures proves to be an efficient substitute to inorganic fertilizers without compromising the yield and also reduces global warming. Under current scenario of global warming and resource sustenance, combination of organic as well as inorganic fertilizers proves to sustain crop production and improve Nutrient Use Efficiency (Verma *et al.,* 2005). Alternate wetting and drying (AWD) water management and suitable N management are two important practices for substance of rice production and their positive interactions on rice yield and N use efficiency determined through coordination of the source-sink relationship (Wang *et al.,* 2016).

MATERIAL AND METHODS

A field experiment was conducted during *rabi* 2020-21 and 2021-22 at Agricultural College Farm, College of Agriculture, Professor Jayashankar Telangana State Agricultural University, Hyderabad with twenty treatments laid out in strip plot design and replicated thrice. The spacing of 20 cm × 15 cm is adopted for transplanted crop while 20 cm × solid row is adopted for direct seeded rice with drum seeder. The plot size is 18 m^2. Seed rate of 20 kg ha^{-1} and 8 kg ha^{-1} is used for transplanted and drum seeded rice, respectively. Buffer channels of 50 cm width was maintained between each plot to prevent water movement. The experimental soil is sandy clay in texture, pH 7.91, EC 0.90 $dSm^{-1,}$ low in organic carbon and available nitrogen (142 kg ha^{-1}), medium in available phosphorous (40 kg ha^{-1}) and high in available potassium (270 kg ha^{-1}). The variety chosen for experiment is Tellahamsa (10754).The treatments consists of 4 vertical plots M_1: Normal Transplanting; M_2: Direct seeded rice with drum seeder; M_3: Normal Transplanting with alternate wetting and drying water management at depletion of 5 cm; M_4: Direct seeded rice with alternate wetting and drying water management at depletion of 5 cm, and five nutrient management practices (horizontal plots) N_1:100% RDN; N_2:75% RDN+25% N Biogas Slurry @ 2.5 t/ ha ;N_3:75% RDN+25% N Azolla compost @1.8 t/ha ; N_4:75% RDN+25% N vermicompost@ 3.1 t/ha ;N_5:75% RDN+ 25%N Poultry Manure @ 2.7 t/ha. Recommended dose of P and K (60:40 kg ha^{-1}) was applied equally to all the plots as basal. Well decomposed organic manures which provide 25% of the recommended dose of nitrogen was incorporated in to the soil 20 days before sowing and transplanting. The 75% inorganic recommended dose of nitrogen is applied in 3 splits 25% N as basal, 25% N at tillering and 25% N at Panicle initiation. Under continuous flooding, the crop was submerged to a depth of 2-5 cm of water, as per the standard practices at different crop growth stages. The N content in biogas slurry, *azolla* compost, vermicompost and poultry manure are 1.5, 2, 1.2 and 1.38% respectively. Under alternate wetting and drying water management system Bowman pipes were placed in the plots between the rows to a depth of 15 cm below the soil surface and 5 cm depth of irrigation was given based on disappearance of ponded water. Water level inside the tube was measured using a simple measuring scale. Water meter was used to measure the quantity of water and water was applied to the field using canvas pipe from the source. Five rice plants were randomly selected and labelled in the net plot and all the biometric observations during the experiment were recorded from these plants. For destructive sampling plants from the border rows were taken.

RESULTS AND DISCUSSION

Plant height (cm) at harvest

Plant height is a direct index to measure the growth and vigor of the plant. Plant height significantly varied among the establishment and water management practices as observed in pooled data at harvest (Table 1). Taller plants were recorded in direct seeded rice with alternate wetting and drying water management at depletion of 5 cm (117 cm) which was on par with transplanting with alternate wetting and drying at depletion of 5 cm (113 cm) while shortest plants were recorded in normal transplanted rice (106 cm). Taller plant height noticed in direct seeded rice (DSR) was due to better plant density and establishment of crop with roots growing deep which takes the efficient uptake of nutrients over transplanted crop (TPR). At harvest plant height is 10.38% higher in direct seeded rice with alternate wetting and drying (AWD) method of water management at depletion of 5 cm over normal transplanting. The results are in line with Gangaiah *et al.* (2019) who stated that wet direct seeded rice recorded taller plants as a result of 1.8 times higher plant density in direct seeded rice as compared to transplanted rice. Significantly taller plants reported in direct seeded rice followed by machine transplanted rice might be due to the lack of transplantation shock in direct seeded plots as stated by Regmi *et al.* (2020), Kumari and Sudheer (2015). Adoption of AWD over continues flooding(CF) promotes aeration to the roots which resulted in taller plants Rahman and Bulbul (2014).

Plant height noticed in 75% RDN+ 25% N poultry manure treated plots were 12.3% taller than the 100% RDN. Application of 75% RDN+ 25% N through poultry manure (118 cm) performed significantly higher plant height (116 cm) over 100% RDN and 75% RDN+ 25% N through biogas slurry. Shorter plants were recorded with 100% RDF (105 cm). Plant height might have increased due to greater availability of nutrients which was also confirmed by Rhaman *et al.* (2016). Whereas, the interaction effect between rice establishment methods, water regimes and nitrogen management practices on plant height at harvest was found to be non-significant.

Dry matter production (kg ha^{-1})

DSR with alternate wetting and drying method of water management at depletion of 5 cm accumulated significantly higher dry matter (7721 kg ha^{-1}) at harvest closely followed by normal transplanting with AWD water management (7597 kg ha^{-1}) as noticed in pooled data closely (Table 1). Lowest dry matter was reported in normal transplanting (7142 kg ha^{-1}). Further the dry matter accumulated in DSR with alternate wetting and drying water management at depletion of 5 cm was 8.10% higher when compared to normal transplanting. Higher accumulation of dry matter in DSR might be due to better establishment of the crop. Taller plants were reported in AWD water management up to PI followed by flooding (3±2cm) which might be due to effective utilization of available resources as a result of good soil aeration in intermittent wetting and drying in sandy loam soils of Karnataka (Theerthana *et al.* 2020). The ability of the canopy to intercept incoming PAR and conversion efficiency of this radiation into biomass determines the plant biomass and its growth. Similar results were also reported by Deeksha *et al.* (2021) who noticed taller rice plants in drum seeded rice.

Dry matter production varied significantly among the N management practices. Application of 75% RDN+ 25% N through poultry manure accumulating maximum amount of dry matter (7942 kg ha^{-1}) over all other N management treatments, while lowest dry matter was observed in 100% RDN (7322 kg ha^{-1}) applied plot. Application of 75% RDN+ 25% N through poultry manure reported 8.46% increase in dry matter over 100% RDN. Taller plants with optimum spacing have led to better availability of resources under drum seeded rice better aeration of soil in intermittent wetting and drying water management combined with 75% RDN + 25% N through organic manure might have resulted in better accumulation of dry matter according to Mohanty *et al.* (2014). The highest total dry matter (22.02g plant^{-1}) was recorded when the crop was fertilized with 25% less than recommended dose of inorganic fertilizers + poultry manure in non-calcareous soils of Bangladesh by Nila *et al.* (2018).

Leaf area index (LAI)

LAI significantly varied among the establishment and water management practices during the period of study (Table 1). Significantly higher LAI (4.04) was recorded in DSR with alternate wetting and drying method of water management closely followed by normal transplanting with alternate wetting and drying (3.94). Whereas, normal transplanted rice recorded least LAI.(3.69) The mean percentage increases of LAI in direct seeded rice was 9.48 % over transplanted rice. As DSR has an opportunity for early establishment and better growth of leaf with AWD water management and with integrated N-nutrient management having a significant effect on the leaf area. The results are in line with Bharathi *et al.* (2019). Maintenance of adequate water supply to plant by flooding and reflooding in AWD helped to put forth higher tiller production an in return higher LAI according to Mote *et al.* (2017). LAI was significantly higher in wet DSR compared to transplanting. (Gautam *et al.,* 2019).

Among the sub treatments 75% RDN+ 25% N through poultry manure recorded higher LAI (4.67) and was significantly superior over the 75% RDN+ 25% N through other organic manures, 100% RDN applied treatment which was least (3.25). Leaf area index is an indicator for area available for photosynthesis which accumulates photosynthates from source to sink. The treatment having combination of organic and inorganic fertilizers showed significant improvement of LAI as reported by Jahan *et al.* (2017).

Days to 50% flowering

Normal transplanting of rice crop with flood irrigation took 93 days to attain 50% flowering which was on par with normal transplanting with AWD water management which took 89 days (Table 1).

Days to 50% flowering was significantly influenced by establishment methods. DSR with AWD matures 10-20 days early than that of transplanted crop. According to Thapliyal *et al.* (2020) direct seeded-aerobic rice took 91 and 121 days to 50 % flowering and days to maturity, respectively which was significantly lower than transplanted rice but was at par with wet direct seeded. Similar results were reported by Nagabhushanam and Bhatt(2020).

Days to 50% flowering also varied significantly among nutrient management practices. Application of 75% RDN+25% N through vermicompost took more number of days (89 days) to attain 50% flowering which was on par with 75% RDN+25% N through *Azolla* compost (88) and 75% RDN+ 25% N through Biogas slurry @ 1.8 t/ha (88 days). Application of 75% RDN+ 25% N through poultry manure took least no of days and 100% RDN took 87 days to attain 50% flowering. More time for attaining 50% flowering in organic manure treated plots might be due to the use of organic nitrogen sources, which might have prolonged the vegetative phases of crop growth. The results are in line with Kumar *et al.* (2016).

No of tillers m^{-2}

Rice establishment methods, irrigation and nutrient management practices has significant influence on no. of tillers (Table 2). Among the main plots direct seeded rice with alternate wetting and drying (298) method of water management recorded significantly higher number of tillers (289 m^{-2}) closely followed by normal transplanting with AWD (293) water management over normal transplanting (271) and the no. of tillers observed in direct seeded rice with alternate wetting and drying at depletion of 5 cm were 9.96% more over normal transplanting. The higher number of tillers in direct seeded rice with AWD might be due to the desired spacing in drum seeded rice which produced more tillers per unit area and provision of suitable micro climate conditions under AWD which increased the number of tillers m^{-2} as reported by Bhardwaj *et al.* (2018). More number of tillers m^{-2} noticed in DSR might be due to closer spacing of sprouted seeds within the solid row which increased number of plants m^{-2} and also maximum number of effective tillers m^{-2} than the conventional transplanting method (Rana *et al.*, 2014)

Among the N-management treatments, application of 75% RDN+25% N through poultry manure (295) performed significantly superior over 75% RDN+25% N through biogas slurry(273) and 100% RDN.Whereas, 75% RDN+25% N through azolla compost(293)and application of 75% RDN+25% N poultry manure (296). Increase in tiller number might be due to integration of inorganic with organic sources (poultry manure) which provide a balanced nutrition to the plant especially micronutrients which is essential for vegetative growth and higher tiller production (Miller 2007). The highest number of total tillers hill^{-1} (16.90) was recorded when fertilized with 25% less than recommended dose of inorganic fertilizers + poultry manure @ 2.5 t ha^{-1} (Nila *et al.,* 2018).

Grain yield (kg ha^{-1})

Grain yield was significantly influenced by rice establishment methods, water regimes and N-management options (Table 2). Direct seeded rice with alternate wetting and drying water management regimes recorded significantly higher grain yield (5530 kg ha^{-1}) over normal transplanted rice (5086 kg ha^{-1}). Normal transplanting with AWD (5495 kg ha^{-1}) and DSR with drum seeded rice (5191 kg ha^{-1}), the grain yields realized were at par with DSR with AWD. Direct seeded rice with alternate wetting and drying performed superior over normal transplanting by 8.72 %. DSR performed superior to all the growth and yield attributes which might have been the reason for higher grain yield compared to transplanting. AWD might have attributed to better nutrient uptake along with root proliferation which encouraged the plants to take more nutrients and water and resulted in better grain and straw yield

Table 1. Effect of rice establishment methods, water management and nitrogen management on Plant Height(cm) , Drymatter(kg ha^{-1}), LAI and Days to 50% Flowering.

	Plant Height (cm)			Drymatter (kg ha^{-1})			LAI			Days To 50% Flowering		
Treatments	**2020**	**2021**	**Pooled**	**2020**	**2021**	**Pooled**	**2020**	**2021**	**Pooled**	**2020**	**2021**	**Pooled**
Vertical plots: Establishment methods and Irrigation management (M)												
M_1: Normal Transplanting(DAT)	105	107	106	7051	7160	7142	3.70	3.68	3.69	91	94	93
M_2: Direct seeded rice with drum seeder	108	110	109	7458	7524	7492	3.79	3.83	3.81	86	88	87
M_3: Normal Transplanting with alternate wetting and drying at depletion of 5 cm (DAT)	113	114	113	7575	7632	7597	3.90	3.99	3.94	81	86	89
M_4: Direct seeded rice with alternate wetting and drying at depletion of 5 cm.	116	118	117	7700	7758	7721	4.01	4.06	4.04	81	83	82
SE(m)±	2.00	2.04	1.87	128	113	110	0.06	0.04	0.04	1.12	1.13	1.35
CD (p=0.05)	6.93	7.05	6.47	442	390	379	0.19	0.13	0.16	4	4	5
Horizontal plots: Nitrogen management (N)												
N_1: 100% RDN	105	106	105	7275	7356	7322	3.22	3.27	3.25	85	88	87
N_2:75% RDN+25% N Biogas Slurry @ 2.5 t/ ha	106	107	107	7328	7367	7334	3.58	3.62	3.60	86	89	88
N_3:75% RDN+25% N *Azolla* Compost @1.8 t/ha	111	113	112	7259	7330	7297	3.84	3.87	3.85	87	90	88
N_4:75% RDN+25% N Vermicompost @ 3.1 t/ha	115	116	115	7526	7579	7545	3.93	4.05	3.99	79	89	87
N_5:75% RDN+ 25%N Poultry Manure @ 2.7 t/ha	117	119	118	7840	7961	7942	4.68	4.65	4.67	87	89	89
SE(m)±	2.3	2.3	2.1	101	121	120	0.14	0.11	0.12	1.06	1.27	0.34
CD (p=0.05)	7.4	7.5	6.9	330	395	390	0.45	0.37	0.41	3	4	1
Interaction												
M×N												
SE(m)±	3.32	3.28	3.10	318	252	249	0.26	0.27	0.25	1.43	1.68	2.17
CD (p=0.05)	NS	NS	NS	NS	762	753	NS	NS	NS	NS	NS	NS
N×M												
SE(m)±	3.43	3.38	3.20	299	249	248	0.28	0.27	0.28	0.37	1.75	1.68
CD (p=0.05)	NS	NS	NS	NS	747	742	NS	NS	NS	NS	NS	NS

Table 2. Effect of rice establishment methods, water management and nitrogen management No of tillers/ m^2, Grain yield (kg ha^{-1}), Straw yield (kg ha^{-1}) and Water use efficiency(kg ha mm^{-1})

Treatments	No of tillers/ m^2			Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})			Water use efficiency		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Vertical plots: Establishment methods and Irrigation management (M)												
M_1: Normal Transplanting(DAT)	268	273	271	5000	5172	5086	6050	6142	6096	3.25	3.34	3.30
M_2: Direct seeded rice with drum seeder	279	285	280	5171	5212	5191	6221	6231	6226	3.54	3.53	3.53
M_3: Normal Transplanting with alternate wetting and drying at depletion of 5 cm (DAT)	290	295	293	5416	5573	5495	6466	6612	6539	3.94	4.04	3.99
M_4: Direct seeded rice with alternate wetting and drying at depletion of 5 cm.	297	299	298	5464	5592	5530	6514	6656	6585	4.47	4.57	4.52
SE(m)±	4.36	5.20	4.77	95	100	100	83	112	103	0.08	0.07	0.08
CD (p=0.05)	15	18	17	330	346	343	290	389	359	0.27	0.28	0.21
Horizontal plots: Nitrogen management (N)												
N_1: 100% RDN	271	276	273	5019	5095	5057	6069	6070	6069	3.61	3.67	3.64
N_2:75% RDN+25% N Biogas Slurry @ 2.5 t/ ha	271	275	273	5104	5272	5189	6154	6313	6233	3.75	3.78	3.76
N_3:75% RDN+25% N *Azolla* Compost @1.8 t/ha	291	296	293	5292	5462	5377	6342	6463	6403	3.81	3.92	3.86
N_4:75% RDN+25% N Vermicompost @ 3.1 t/ha	292	296	294	5327	5432	5380	6377	6450	6413	3.83	3.90	3.86
N_5:75% RDN+ 25%N Poultry Manure @ 2.7 t/ha	293	298	295	5572	5674	5624	6622	6756	6689	4.02	4.08	4.05
SE(m)±	5.55	4.77	5.14	110	111	110	110	92	96	0.11	0.09	0.10
CD (p=0.05)	18	16	17	358	361	358	358	301	314	NS	NS	NS
Interaction												
M×N												
SE(m)±	14.88	14.86	14.84	157	175	160	157	186	163	0.19	0.16	0.17
CD (p=0.05)	NS	NS	NS	488	542	501	488	581	509	NS	NS	NS
N×M												
SE(m)±	14.85	14.30	14.55	163	178	164	163	171	157	0.20	0.17	0.18
CD (p=0.05)	NS	NS	NS	501	543	503	501	517	479	NS	NS	NS

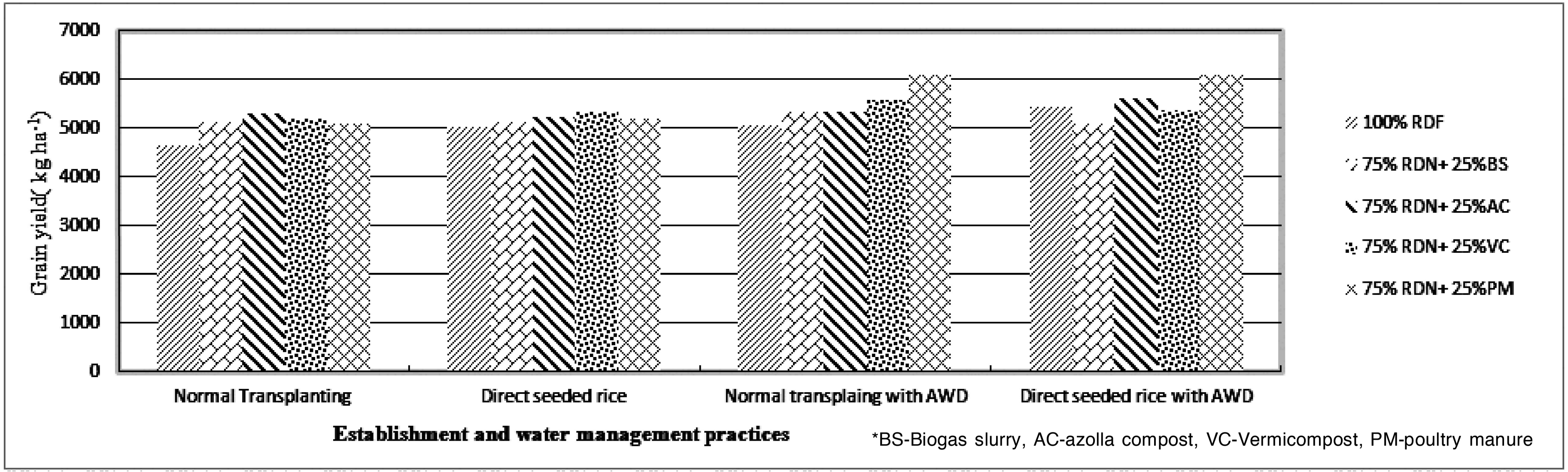

Figure 1. Interaction effect of rice establishment methods, water regimes and nitrogen management practices on grain yield of rice (Pooled data)

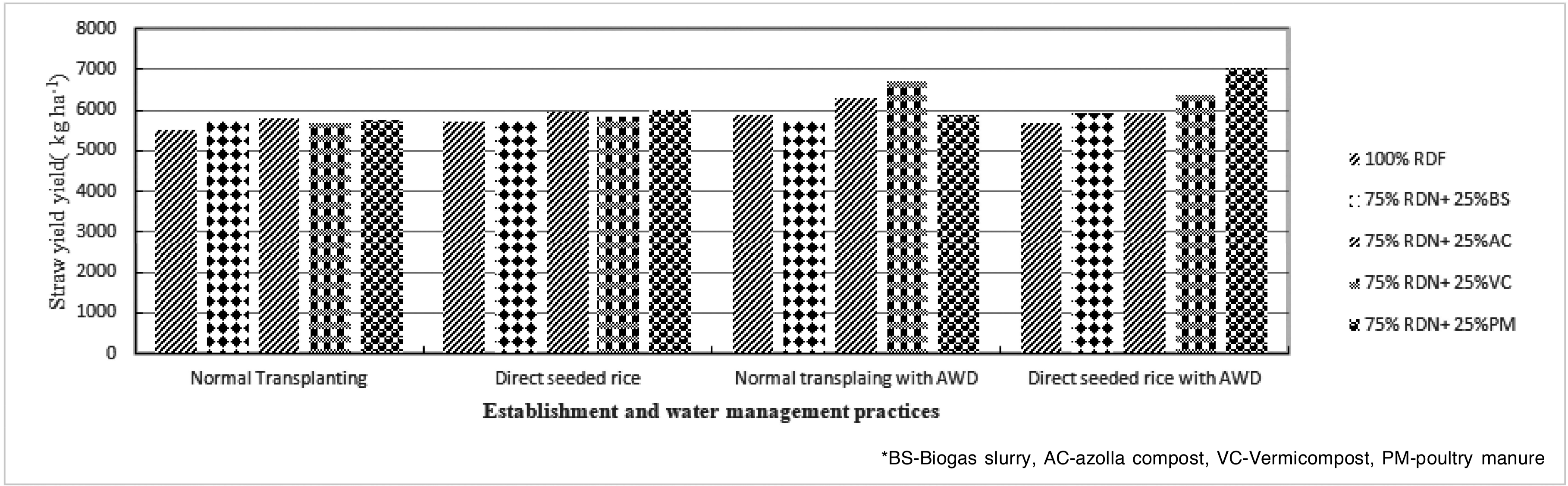

Figure 2. Interaction effect of rice establishment methods, water regimes and nitrogen management practices on straw yield of rice (Pooled data)

according to Pascual and Wang (2016) and Ndiiri *et al.* (2012). Similar results were also reported by Sharma *et al.* (2016) and Bharathi *et al.* (2019).

N management practices have a significant influence on grain yield of rice. Among the organic manures application of 75% RDN+ 25% N through poultry manure recorded significantly higher grain yield (5624 kg ha^{-1}) over 100% RDF (5057) and 75% RDN+ 25% RDN through biogas slurry (5189 kg ha^{-1}), 75% RDN+ 25% RDN through vermicompo crop growth and yield and the results are in line with Ahmed *et al.* (2014). The interaction effect of establishment methods, water regimes and nutrient management practices was found to be significant for grain yield as elucidated in Figure 1.

Straw yield (kg ha^{-1})

Rice establishment methods, irrigation regimes and nitrogen management practices have significantly influenced straw yield (Table 2). Direct seeded rice with alternate wetting and drying method of water management recorded significantly higher straw yield of 6585 kg ha^{-1} over normal transplanting (6096 kg ha^{-1}) and direct seeding with drum seeder (6226 kg ha^{-1}). The straw yield observed in DSR with AWD might be due to higher dry matter accumulation higher as a result of improved soil nutrient absorption, increased metabolic processes, high rate of light absorption, and photosynthetic activity with greater number of leaves and also which facilitated more grain yield in drum seeded rice with corresponding biological yield. Similar results were reported by Tadepalli and Singh (2017).

Among the nitrogen management practices 75% RDN+25% RDN through poultry manure recorded significantly higher straw yield (6689 kg ha^{-1}) over 100% RDN and 75% RDN+25% RDN through biogas slurry. This might be due to adequate supply of nitrogen throughout crop growth period under poultry manure that led to higher dry matter production according to Saha *et al.* (2013). Significant interaction effect was observed on straw yield by of rice establishment methods, water management practices and organic manures as presented in Figure 2.

Water use efficiency (WUE)

Water use efficiency (WUE) in rice was higher in DSR with AWD (4.52 kg ha mm^{-1}) followed by normal transplanting with alternate wetting and drying at depletion of 5 cm (3.99 kg ha mm^{-1})(Table 2). The lowest WUE was accounted with normal transplanting (3.30 kg ha mm^{-1}) respectively. Higher WUE was due to a lower water requirement in the case of alternate wetting and drying conditions and also direct seeded rice requires less water compared to normal transplanting. Sathish *et al.* (2017) reported higher WUE in the treatment where irrigation was scheduled when water level falls below 10 cm from soil surface in field water tube.

Application of 75% RDN + 25%N poultry manure @ 2.7 t/ha (4.05 kg ha mm^{-1}) reported numerically higher water use efficiency followed by 75% RDN+25% N vermicompost @ 3.1 t/ha (3.86 kg mm^{-1}) and 75% RDN+25% N *Azolla* compost @1.8 t/ha. There is no significant effect of nitrogen management practices on WUE.

CONCLUSION

From the above study it can be concluded that direct seeded rice with alternate wetting and drying method of water management at depletion of 5 cm along with 75% RDN+ 25% N through poultry manure @ 2.7 t/ha is closely followed by normal transplanting with AWD combined with 75% RDN+ 25% N through poultry manure are effective practices to achieve higher growth, grain and straw yields with reduction in water input and nutrient management, depth of water, soil temperature influences various there by helps in achieving the sustainable rice cultivation and helps preserving resources for future generations.

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Research Article
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SEED HANDLING TECHNOLOGY AND STORAGE BEHAVIOUR OF SALES RETURN SEED UNDER COLD STORAGE CONDITIONS IN MAIZE (*Zea mays* L.)

A. AKHIL REDDY[1], P. SUJATHA[1], P. JAGAN MOHAN RAO[2], A. NOOKA RAJU[3], K. RAGHAVENDRA[4] and S.N.C.V.L. PUSHPAVALLI[5]

[1]Department of Seed Science & Technology, College of Agriculture, Rajendranagar

[2]Department of Plant Breeding, Seed Research & Technology Centre, Rajendranagar

[3]Department of Seed Technology, Manager, Quality Assurance, Kaveri Seed Company Ltd., Siddipet

[4]Department of Agri-Biotechnology, National Project Coordinator, Indo-German Cooperation on Seed Sector Development

[5]Department of Biotechnology, Institute of Biotechnology, College of Agriculture, Rajendranagar

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ABSTRACT

An experiment to know effect of handling technology on storage behaviour of sales return maize seed after 2 months of cold storage was conducted during 2020 and 2021 in cold storage unit of Kaveri Seed Company Limited. Maize seed of 218+ and Profit each with three different lots, Fresh seed, one time and two times sales returned seeds (Q3) were packed in 4 different packing materials, transported and stored at retailer stores for different months (one, two & three months) under ambient conditions. After completion of predetermined interval seed was brought back, stored for 2 months under cold storage and its effect on seed moisture content (SMC) and seed germination (SG) were recorded. Fresh and One time sales returned seed of 218+ showed significantly low SMC (11.3 and 11.3%). But two times sales returned seed of 218+ and Profit hybrids showed significantly high SMC (11.5 and 11.8 %). Seed of 218+ and Profit packed in Savegrain (P2), Polypouch (P1) and Triple layer bag (P3) recorded significantly lower pooled mean SMC (11.2, 11.3 and 11.3 %) when compared to Recyclable (P4) bag (11.6 and 11.4 %, respectively). Fresh and One time sales returned seed of 218+ hybrid showed significantly high seed germination (95 and 95%) compared to two times sales returned seed (53%). Seed of 218+ packed in Savegrain (P2), Polypouch (P1) and Triple layer bag (P3) recorded significantly higher pooled mean seed germination (82, 81 and 81 %) when compared to Recyclable bag (80%). Profit seed recorded significantly high seed germination (92%) even after 3 months of storage at retailer. Whereas 218+, recorded higher SG (83 %) only for one month at retailer.

Key words: Maize, seed lots, sales returns, packaging materials, cold storage.

Maize (*Zea mays* L.) is the third most important cereal crop after wheat and rice with high nutritional value and serving as a basic raw material for production of starch, oil, protein, alcoholic beverages and fuel. It also provides raw materials for corn oil, corn syrup, sugar, corn meal and corn flour and occupies an important place in Indian agriculture (Madhukeshwara and Sajjan, 2015). Maize kernel is the edible and nutritive part of the plant. It is a rich source of vitamin C, vitamin E, vitamin K, vitamin B, folic acid, selenium, N-p-coumaryl tryptamine, and N-ferrulyl tryptamine. Potassium is a major nutrient present which has a good significance because an average human diet is deficient in it (Kumar and Jhariya, 2013). Maize germ contains about 45–50% of oil that is used in cooking, salads which is obtained from wet milling process (Orthoefer *et al.,* 2003).

Globally India is in fourth position in terms of area of cultivation and seventh in production of maize with an annual production of 31.6 million tonnes (India stat, 2020-21). It is the second major cultivated crop in the state of Telangana with production of 2.6 million tonnes with the productivity of 6,782 Kgha^{-1} in 2020-21. The major districts growing maize in Telangana are Karimnagar, Warangal (Rural), Warangal (Urban), Nizamabad, Mahaboobnagar, Medak, Khammam, Nizamabad and Jagtial districts covering an area of 0.8 million hectares (India stat, 2020-21).

Maize seed companies are offering farmers a wide range of improved hybrids producing a huge quantity of seed every year. Certain quantity of it will be marketed according to the demand. Presently, seed industry is facing very high inventory loss of 25-30 per cent due to the increase in the percentage of sales return (Goncalves and Rice, 2003). The left over or unsold seeds brought back from the respective retailer/ distributor is called "Sales Returns seed" (Goncalves, 2008). The rate of deterioration of seeds increases with number returns. This issue is leading to a loss of thousands of tonnes of seeds every year under

Email: akhilreddy9119@gmail.com

improper inventory management. The standardization of technology for safe handling and storage of sales return seed in maize helps to address the critical issues being faced by the Indian seed industry.

The seed company pays for all costs associated with returns, which includes transportation, testing, reconditioning, repackaging and discards. Even when the storage conditions at the dealers are satisfactory, the seeds must still be tested and repackaged. Many times, however, seeds stored in poor conditions need to be discarded. Corn seed has a maximum three-year shelf life. In a business characterized by revenues of US$ 200 million, the costs associated with transportation, repackaging, retesting, reconditioning and lost sales reach about 10% of the total (Goncalves and Rice 2003).

Maize seed undergoes periods of initial cold followed by ambient and restorage under cold periods in case of sales returns. The present study was conducted to identify problems at different levels of seed handling and to suggest suitable management strategy to minimize deterioration in sales return seed lots.

MATERIAL AND METHODS

The experiment was conducted to know the effect of seed handling technology on the storage behaviour of sales return maize seed after two months of cold storage during 2020 and 2021 in the cold storage unit of Kaveri Seed Company Limited, Gouraram, Pamulaparthy, Medchal. Maize seed of three quality lots i.e., Fresh seed (Q1), One time (Q2) and Two times sales returned seed (Q3) each from two hybrids viz., 218+ (H1) and Profit (H2) were brought out from the cold storage and stored under ambient conditions for 24 hours for acclimatization. The seed was treated according to the industry recommended practice, weighed and packed in four different packaging materials i.e., Polypouch bags (P1), Savegrain bags (P2), Triple layer bags (P3) and Recyclable bags (P4). The treatment units were transported to the retailer and brought back at regular intervals of one, two and three months of time to the experimental site and placed in the cold storage unit for a period of two months and then seed quality parameters were recorded.

Before initiation of the experiment, the initial seed quality parameters of the three lots each of two hybrids were recorded. During 2020, Two times sales return seed of 218+ hybrid recorded very low initial seed germination (34 %) because of which the pooled mean values of the same lot also showed very low seed germination. During 2021, this problem was rectified by taking first year one time returned seed lot as two times returned seed lot. The experiment was laid out in three factorial Completely Randomized Design with each treatment replicated thrice. Data on following seed quality parameters were recorded at specific intervals.

Seed Moisture Content (%): The moisture content of the maize seed was determined according to the ISTA validated high constant temperature oven method (ISTA, 2019).

Seed germination (%): Maize seed germination was determined according to the ISTA validated Between Paper (BP) method (ISTA, 2019).

Data Analysis

The data were analyzed statistically by applying Panse and Sukhatme (1985) pooled three factorial Completely Randomized Design (CRD) and the standard error of difference was determined at the 5% probability level to compare the mean difference between the treatments.

RESULTS AND DISCUSSION

The effect of handling technology on the storage behaviour of sales return maize seed after two months of cold storage on seed moisture content (SMC) and seed germination (SG) was presented in Tables 1a, 1b, 2a and 2b.

Effect of Handling Technology on Seed Moisture Content (%) After two Months of Cold Storage During 2020 and 2021

The data pertaining to the effect of handling technology on Seed Moisture Content (%) after 2 months of cold storage during 2020 and 2021 were presented in the Table 1a and 1b.

Effect of quality of seed lot (F1) on seed moisture content under cold storage

Fresh seed lot (Q1) of 218+ and Profit and one time sales returned seed lot (Q2) of 218+ showed significantly lower pooled mean seed moisture content (11.3, 11.0 and 11.3%, respectively) compared to two times returned (Q3) seed lots of the same hybrids (11.5 and 11.8 % respectively). This indicates that with an

Table 1a. Effect of handling technology on seed moisture content (%) of sales return maize seed after 2 months of cold storage of maize hybrids (218+) and (Profit)

Factor	Genotypes					
	218+			Profit		
	2020	**2021**	**Pooled**	**2020**	**2021**	**Pooled**
Factor (A)						
Q1- Fresh seed	10.4*	12.1*	11.3*	10.1*	11.8	11.0*
Q2- One time sales returned	10.4*	12.1*	11.3*	10.9	11.4*	11.1
Q3- Two times sales returned	10.7	12.2	11.5	10.9	12.6	11.8
C.D. (0.05)	**0.087**	**0.069**	**0.055**	**0.079**	**0.079**	**0.055**
Factor (B)						
P1- Polypouch	10.4*	12.1*	11.3*	10.6	11.9	11.3*
P2- Savegrain	10.4*	12.0*	11.2*	10.6	11.9	11.3*
P3- Triple layer	10.4*	12.1*	11.3*	10.6	11.9	11.3*
P4- Recyclable	10.9	12.2	11.6	10.7	12.0	11.4
C.D. (0.05)	**0.101**	**0.080**	**0.063**	**0.092 N**	**0.091 N**	**0.064**
Factor (C)						
M1 - One month ambient retailer storage followed by 2 months cold storage	10.6	12.1*	11.4	10.6	11.8*	11.2*
M2 - Two months ambient retailer storage followed by 2 months cold storage	10.5	12.1*	11.4	10.6	11.8*	11.2*
M3 - Three months ambient retailer storage followed by 2 months cold storage	10.5	12.2	11.4	10.6	12.0	11.3
C.D. (0.05)	**0.087 N**	**0.069**	**0.055 N**	**0.079 N**	**0.079**	**0.055**

*P = 0.05
'N':- Non-significant

Table 1b. Interaction effect of quality of seed lot (F1), packaging material (F2) and months of storage at retailer (F3)

Treatments	Quality of seed lot (F1)	Packaging material (F2)	Months of storage at Retailer (F3)	SMC (%) / (218+)			SMC (%) / Profit		
				2020	2021	Pooled	2020	2021	Pooled
T1	Fresh	Polypouch	One	10.2	12.2	11.2*	10.1	12.1	11.1
T2	Fresh	Polypouch	Two	10.3	12.7	11.5	10.1	11.7	10.9*
T3	Fresh	Polypouch	Three	10.2	12.3	11.3	10.1	12.0	11.1
T4	Fresh	Save grain	One	10.3	12.0	11.2*	10.2	11.6	10.9*
T5	Fresh	Save grain	Two	10.2	11.8	11.0*	10.0	11.5	10.7*
T6	Fresh	Save grain	Three	10.3	12.1	11.2*	10.1	11.6	10.8*
T7	Fresh	Triple layer	One	10.2	12.1	11.2*	10.2	11.9	11.1
T8	Fresh	Triple layer	Two	10.3	12.9	11.6	10.0	11.5	10.8*
T9	Fresh	Triple layer	Three	10.2	12.0	11.1*	10.1	11.8	11.0
T10	Fresh	Recyclable	One	10.9	12.1	11.5	10.3	12.2	11.3
T11	Fresh	Recyclable	Two	10.7	11.8	11.3	9.9	11.6	10.8*
T12	Fresh	Recyclable	Three	10.8	12.2	11.5	9.9	11.7	10.8*
T13	One time	Polypouch	One	10.2	11.9	11.1*	10.7	11.5	11.1
T14	One time	Polypouch	Two	10.3	12.0	11.2*	10.9	11.1	11.0
T15	One time	Polypouch	Three	10.3	12.4	11.4	10.7	11.7	11.2
T16	One time	Save grain	One	10.2	12.0	11.1*	10.8	11.4	11.1
T17	One time	Save grain	Two	10.2	12.2	11.2*	10.8	11.1	11.0
T18	One time	Save grain	Three	10.3	12.2	11.3	11.0	11.6	11.3
T19	One time	Triple layer	One	10.2	12.0	11.1*	10.9	11.1	11.0
T20	One time	Triple layer	Two	10.3	12.0	11.2*	11.0	11.1	11.1
T21	One time	Triple layer	Three	10.2	12.1	11.2*	10.8	11.5	11.2
T22	One time	Recyclable	One	11.1	12.2	11.7	11.0	11.4	11.2
T23	One time	Recyclable	Two	11.1	11.8	11.5	11.1	11.3	11.2

Treatments	Quality of seed lot (F1)	Packaging material (F2)	Months of storage at Retailer (F3)	SMC (%) / (218+)			SMC (%) / Profit		
				2020	2021	Pooled	2020	2021	Pooled
T24	One time	Recyclable	Three	10.6	12.2	11.4	11.0	11.5	11.3
T25	Two times	Polypouch	One	10.8	12.2	11.5	11.0	12.5	11.8
T26	Two times	Polypouch	Two	10.5	12.2	11.4	10.7	12.4	11.6
T27	Two times	Polypouch	Three	10.6	12.3	11.5	10.7	12.5	11.6
T28	Two times	Save grain	One	10.7	12.0	11.4	10.7	12.5	11.6
T29	Two times	Save grain	Two	10.7	12.0	11.4	10.9	12.4	11.7
T30	Two times	Save grain	Three	10.5	12.3	11.4	10.7	12.8	11.8
T31	Two times	Triple layer	One	10.9	11.7	11.3	11.0	12.5	11.8
T32	Two times	Triple layer	Two	10.7	11.9	11.3	11.0	12.7	11.9
T33	Two times	Triple layer	Three	10.7	12.0	11.4	10.6	12.8	11.7
T34	Two times	Recyclable	One	11.1	12.8	12.0	11.1	12.7	11.9
T35	Two times	Recyclable	Two	10.8	12.3	11.6	11.1	12.6	11.9
T36	Two times	Recyclable	Three	10.8	12.2	11.5	11.1	12.7	11.9
Grand Mean				**10.5**	**12.1**	**11.3**	**10.6**	**11.9**	**11.3**
C.V %				**1.416**	**0.972**	**1.186**	**1.275**	**1.127**	**1.197**
A		**SE (m)**		0.030	0.024	0.019	0.028	0.027	0.019
		CD		0.087	0.069	0.055	0.079	0.079	0.055
B		**SE (m)**		0.035	0.028	0.022	0.032	0.032	0.023
		CD		0.101	0.080	0.063	0.092	0.091	0.064
C		**SE (m)**		0.030	0.024	0.019	0.028	0.027	0.019
		CD		0.087	0.069	0.055	0.079	0.079	0.055
A×B		**SE (m)**		0.061	0.048	0.039	0.055	0.055	0.039
		CD		0.175	0.139	0.110	0.159	0.158	0.110

Treatments	Quality of seed lot (F1)	Packaging material (F2)	Months of storage at Retailer (F3)	SMC (%) / (218+)			SMC (%) / Profit		
				2020	2021	Pooled	2020	2021	Pooled
A×C		SE (m)		0.053	0.042	0.034	0.048	0.048	0.034
		CD		0.152	0.120	0.095	0.138	0.137	0.095
B×C		SE (m)		0.061	0.048	0.039	0.055	0.055	0.039
		CD		0.175	0.139	0.110	0.159	0.158	0.110
A×B×C		SE (m)		0.106	0.084	0.067	0.096	0.095	0.068
		CD		**0.303**	**0.240**	**0.190**	**0.275**	**0.273**	**0.191**

*P = 0.05

Table 2a. Effect of handling technology on seed germination % of sales return maize seed after 2 months of cold storage of maize hybrids (218+) and (Profit)

Factor	Genotypes					
	218+			Profit		
	2020	**2021**	**Pooled**	**2020**	**2021**	**Pooled**
Factor (A)						
Q1- Fresh seed	94 *	95 *	95 *	90	93 *	92
Q2- One time sales returned	94 *	95 *	95 *	92 *	89	91
Q3- Two times sales returned	24	82	53	89	92 *	91
C.D. (0.05)	**1.063**	**1.228**	**0.798**	**0.755**	**1.209**	**0.700 N**
Factor (B)						
P1- Polypouch	71 *	92 *	81 *	90	92 *	91
P2- Savegrain	71 *	92 *	82 *	90	91	91
P3- Triple layer	71 *	91 *	81 *	91	90	91
P4- Recyclable	69	90	80	90	90	90
C.D. (0.05)	**1.227**	**1.418**	**0.921**	**0.872 N**	**1.396**	**0.809 N**
Factor (C)						
M1 - One month ambient retailer storage followed by 2 months cold storage	74 *	92 *	83 *	90	92 *	91 *
M2 - Two months ambient retailer storage followed by 2 months cold storage	70	90	80	90	90	90
M3 - Three months ambient retailer storage followed by 2 months cold storage	68	90	79	92 *	91 *	92 *
C.D. (0.05)	**1.063**	**1.228**	**0.798**	**0.755**	**1.209**	**0.700**

*P = 0.05
'N':- Non-significant

Table 2b. Interaction effect of quality of seed lot (F1), packaging material (F2) and months of storage at retailer (F3)

Treatments	Quality of seed lot (F1)	Packaging material (F2)	Months of storage at Retailer (F3)	Genotypes					
					(218+)			Profit	
				2020	2021	Pooled	2020	2021	Pooled
T1	Fresh	Polypouch	One	92 *	94 *	**93 ***	90	94 *	**92 ***
T2	Fresh	Polypouch	Two	94 *	92	**93 ***	86	91	**89**
T3	Fresh	Polypouch	Three	95 *	96 *	**96 ***	91 *	94 *	**93 ***
T4	Fresh	Save grain	One	94 *	96 *	**95 ***	91	92	**92 ***
T5	Fresh	Save grain	Two	94 *	96 *	**95 ***	93 *	92	**93 ***
T6	Fresh	Save grain	Three	94 *	96 *	**95 ***	91 *	94 *	**93 ***
T7	Fresh	Triple layer	One	94 *	93	**94 ***	87	95 *	**91**
T8	Fresh	Triple layer	Two	95 *	93	**94 ***	89	93 *	**91**
T9	Fresh	Triple layer	Three	95 *	96 *	**96 ***	92 *	92	**92 ***
T10	Fresh	Recyclable	One	94 *	96 *	**95 ***	92 *	96 *	**94 ***
T11	Fresh	Recyclable	Two	90	96 *	**93 ***	90	87	**89**
T12	Fresh	Recyclable	Three	93 *	98 *	**96 ***	90	97 *	**94 ***
T13	One time	Polypouch	One	94 *	95 *	**95 ***	92 *	93 *	**93 ***
T14	One time	Polypouch	Two	91 *	97 *	**94 ***	94 *	89	**92 ***
T15	One time	Polypouch	Three	93 *	95 *	**94 ***	94 *	91	**93 ***
T16	One time	Save grain	One	95 *	96 *	**96 ***	89	86	**88**
T17	One time	Save grain	Two	94 *	98 *	**96 ***	93 *	84	**89**
T18	One time	Save grain	Three	94 *	95 *	**95 ***	93 *	82	**88**
T19	One time	Triple layer	One	93 *	93	**93 ***	92 *	86	**89**
T20	One time	Triple layer	Two	94 *	92	**93 ***	92 *	83	**88**
T21	One time	Triple layer	Three	93 *	94 *	**94 ***	92 *	90	**91**
T22	One time	Recyclable	One	95 *	97 *	**96 ***	92 *	85	**89**
T23	One time	Recyclable	Two	94 *	95 *	**95 ***	89	85	**87**

Treatments	Quality of seed lot (F1)	Packaging material (F2)	Months of storage at Retailer (F3)	Genotypes					
				(218+)			Profit		
				2020	2021	Pooled	2020	2021	Pooled
T24	One time	Recyclable	Three	92*	92	**92**	94*	83	**89**
T25	Two times	Polypouch	One	35	87	**61**	87	96*	**92***
T26	Two times	Polypouch	Two	23	88	**56**	88	89	**89**
T27	Two times	Polypouch	Three	18	83	**51**	90	90	**90**
T28	Two times	Save grain	One	32	92	**62**	88	94*	**91**
T29	Two times	Save grain	Two	26	74	**50**	81	92	**87**
T30	Two times	Save grain	Three	16	88	**52**	92*	95*	**94***
T31	Two times	Triple layer	One	39	83	**56**	92*	94*	**93***
T32	Two times	Triple layer	Two	15	85	**50**	93*	82	**88**
T33	Two times	Triple layer	Three	21	70	**46**	93*	92	**93***
T34	Two times	Recyclable	One	31	93	**62**	88	90	**89**
T35	Two times	Recyclable	Two	24	73	**49**	85	93*	**89**
T36	Two times	Recyclable	Three	12	74	**43**	89	92	**91**
Grand Mean				**70**	**90**	**80**	**90**	**90**	**90**
C.V %				**2.582**	**2.319**	**2.440**	**1.430**	**2.290**	**1.909**
A		**SE (m)**		0.370	0.428	0.283	0.263	0.421	0.248
		CD		1.063	1.228	0.798	0.755	1.209	0.700
B		**SE (m)**		0.427	0.494	0.327	0.304	0.486	0.287
		CD		1.227	1.418	0.921	0.872	1.396	0.809
C		**SE (m)**		0.370	0.428	0.283	0.263	0.421	0.248
		CD		1.063	1.228	0.798	0.755	1.209	0.700
A×B		**SE (m)**		0.740	0.855	0.566	0.526	0.842	0.497
		CD		2.126	2.455	1.595	1.511	2.418	1.401
A×C		**SE (m)**		0.641	0.741	0.490	0.456	0.729	0.430

Treatments	Quality of seed lot (F1)	Packaging material (F2)	Months of storage at Retailer (F3)	Genotypes					
					(218+)			Profit	
				2020	**2021**	**Pooled**	**2020**	**2021**	**Pooled**
			CD	1.841	2.127	1.382	1.308	2.094	1.213
B×C			**SE (m)**	0.740	0.855	0.566	0.526	0.842	0.497
			CD	2.126	2.455	1.595	1.511	2.418	1.401
A×B×C			**SE (m)**	1.282	1.481	0.980	0.911	1.459	0.860
			CD	3.682	**4.253**	**2.763**	**2.617**	**4.189**	**2.426**

*P = 0.05

increase in ageing period there was a concurrent rise in seed moisture content. Seed of two times sales returns might have been exposed to alternate cold and ambient storage conditions for three times (thermal shock) which might have increased its membrane permeability. In addition to this, the age of two times returns might have also contributed to gain in the seed moisture content suggesting that greater sensitivity of longevity to the accelerated ageing time duration (Jain *et al.,* 2006 and Neelesh *et al.,* 2011). Aged seed respires more and increase in ageing results in progressive decline in all the vital events occur culminating to death at the end. These findings are in conformity with Radha *et al.* (2014) who have reported that accelerated ageing period has recorded highest moisture content and are lower in unaged seed. The outer and inner membranes appeared as potential targets for desiccation and ageing injuries in seeds, seed ageing may cause activity alteration of low plasma membrane ATPase activity (Bardel *et al.*, 2002).

Effect of packaging material (F2) on seed moisture content under cold storage

The effect of packaging material on the seed quality during transit and ambient storage was studied to identify the best packaging material for sales return seeds. Irrespective of hybrids, seed packed in Savegrain (P2), Polypouch (P1) and Triple layer bag (P3) recorded significantly lower pooled mean seed moisture (11.2 to 11.3 %). Significantly high seed moisture content was recorded with Recyclable (P4) bag in both the hybrids (11.4 and 11.6 %, respectively in Profit and 218+). In both hybrids (218+ and profit) Polypouch (P1), Savegrain (P2) and Triple layer bags (P3) showed consistency in the trend during both the consecutive years of study (pooled mean values). This might be due to the moisture impervious and vapour impervious nature of the bags.

From the above findings it is to conclude that Polypouch (P1), Savegrain (P2) and Triple layer bag (P3) are more efficient for safe handling for 2 months cold storage of sales return seed of 218+ and Profit hybrid without any increase in seed moisture content compared to recyclable bag (P4).

The use of hermetic storage reduces the influence of many of the environmental factors that contribute to seed viability and vigour loss by preventing rewetting, which can help to keep seed quality high. Hermetic nature of Polypouch, Savegrain and Triple layer bags might have minimized the moisture and gaseous exchange which might have slowed down the rate of oxidative deterioration. Similar findings were also recorded in maize by Guberac *et al.* (2003). The finding confirms earlier study that showed the moisture content of maize grains stored in the hermetic bags remains unchanged during storage period (Kukom *et al.,* 2013) and further confirmed with **Likhayo *et al.* (2018).**

Effect of months of storage under ambient conditions at retailer store (F3) on seed moisture content under cold storage

Irrespective of months of storage under ambient conditions at retailer the seed of maize hybrid 218+ showed no significant difference in seed moisture (11.4 %). Whereas, in Profit hybrid upto two months of storage at retailer followed by two months cold storage recorded significantly lower seed moisture (11.2 %) when compared to three months of storage at retailer followed by two months cold storage (11.3 %). This was in conformity with the findings reported in maize (Lane *et al.*, 2017 and Bhandari *et al.*, 2017) that the seed moisture content increased as the storage period increased.

Combined effect of F1, F2, F3 on seed moisture content under cold storage

The mean pooled seed moisture content recorded in 218+ and Profit was 11.3 %. In both the hybrids comparatively lower mean seed moisture was recorded in the first year (10.5 and 10.6 %, respectively for 218+ and Profit) than in the second year (12.1 and 11.9 %, respectively for 218+ and Profit).

After two months of storage under cold conditions, irrespective of hybrids, fresh seed packed in savegrain bag stored for two months at retailer (T5) recorded significantly low SMC (11.0 and 10.7%, respectively for 218+ and profit). Irrespective of months of storage under ambient conditions, fresh seed of 218+, packed in savegrain and one time sales returned seed packed in triple layer recorded significantly lower seed moisture content (T4, T6, T19, T20 and T21) and T2, T4, T6, T8, T11 and T12 of Profit recorded significantly low seed moisture content.

Irrespective of packing material and months of storage at retailer, two times sales return seed recorded significantly high SMC in both 218+ and Profit (11.3 – 12.0 % and 11.6-11.9 %, respectively).

Effect of Handling Technology on Seed Germination (%) After two Months of Cold Storage During 2020 and 2021

The data pertaining to the effect of handling technology on Seed Germination (%) after 2 months of cold storage during 2020 and 2021 were presented in the Table 2a and 2b.

Effect of quality of seed lot (F1) on seed germination under cold storage

Fresh seed lot (Q1) and one time sales returned seed lot (Q2) of maize hybrid 218+ showed significantly higher pooled mean seed germination (95 %) but the seed of two times returned seed lot (Q3) showed very low germination (53 %). Similar trend of performance was observed during both the consecutive years of study. This might be due to the fact that with the advancement of age of seed, the metabolic activity reduces due to increased activity of peroxidation and loss in membrane integrity leading to programmed cell death. However seed of Fresh (Q1), one time returned (Q2) and two times sales returned seed lots (Q3) of Profit showed numerically high seed germination (>91 %) under similar conditions of storage with statistically no significant difference among the seed lots. The thermal shock advantage of Profit maize hybrid might be attributed to its genetic constitution as it is a single cross hybrid compared to 218+ which is a three way cross hybrid. These findings are in conformity with Oluwaranti *et al.* (2018) who have reported that single cross hybrid was observed to have the highest germination percentage in maize when compared to three way cross hybrid.

From the above findings it is to conclude that fresh and one time returned seed of 218+ can safely be stored under cold conditions without drastic decrease in seed germination but not two times returned seed. Whereas in case of Profit, in addition to fresh and one time returned seed two times returned seed can also be safely stored under cold conditions upto two months without any loss in seed germination. This indicates that the effect of transit and ambient storage conditions influences the quality of seed lot. These findings are in further with Radha *et al.* (2014) who have reported that accelerated ageing resulted in decreased germination percentage of maize. The decrease in germination and increase in abnormal seedlings, dead seeds by accelerated ageing may be a result of progressive loss of seed viability and vigor (Jain *et al.*, 2006).

Effect of seed packaging material (F2) on seed germination under cold storage

Seed packed in Savegrain (P2), Polypouch (P1) and Triple layer (P3) bags recorded significantly higher mean seed germination in 218+ hybrid (82, 81 and 81 %, respectively) during both the consecutive years of study (pooled mean values). Comparatively, less germination was recorded in Recyclable (P4) bag (80 %). Polypouch (P1), Savegrain (P2) and Triple layer (P3) bags showed consistency in the trend during both the years of study. But in Profit, packing material recorded no significant influence on seed germination after 2 months of storage under cold conditions. But polypouch (P1), savegrain (P2) and triple layer bag (P3) showed numerically high seed germination (91 %) in the same hybrid under similar conditions of storage.

Due to the hermetic nature of Polypouch, Savegrain and Triple layer bag the oxidation reactions might have been minimized under ambient storage conditions which were in conformity with the findings reported in soybean (Kandil *et al.*, 2013). Similar findings were reported by El-Sayed and Tolba (2005) which was further supported by Shabana (2015).

From the above findings it is to conclude that three packing materials i.e., Polypouch (P1), Savegrain (P2) and Triple layer bag (P3) can be used for safe storage of sales returned seed of 218+ and Profit without any loss in seed germination but not recyclable bag (P4).

Effect of months of storage under ambient conditions at retailer store (F3) on seed germination under cold storage

After two months of storage under cold conditions, seed of 218+ hybrid, stored for one month at retailer store showed significantly higher pooled mean seed germination (83 %) compared to the seed stored for two and three months (80 and 79 %, respectively). During 2021, two and three months stored 218+ seed also recorded numerically high germination

(90 %). Whereas, after two months of storage under cold conditions, seed of Profit recorded significantly high seed germination (92%) even after three months of ambient storage at retailer store. This indicates that three months of ambient storage period followed by two months of cold storage retained good seed germination in the seed of Profit but not in 218+.

This was in conformity with the findings of Rai *et al.*, 2011 and Borza *et al.*, 2017 who reported that the maize seed germination % decreased with the increase in the storage period. The findings were further supported by Garoma *et al.* (2017) indicating that germination decreased as the seed stored for longer period and significant decline was observed after one year storage in maize (Mrda *et al.,* 2010).

Combined effect of F1, F2, F3 on seed germination under cold storage

Pooled mean seed germination recorded in 218+ and Profit was 80% and 90%, respectively.

Fresh seed of 218+ hybrid packed in either Polypouch, Triple layer or Recyclable bag which is stored for three months under ambient conditions followed by two months of cold storage (T3, T9 and T12) and one time returned seed packed in Savegrain bag and stored under ambient conditions either for one month (T16) or two months (T17) followed by two months of cold storage and one time returned seed packed in recyclable bag and stored under ambient conditions for one month (T22) followed by two months of cold storage recorded highest pooled mean seed germination of 96%. Whereas, under same conditions highest pooled mean seed germination of 94% was recorded in the fresh seed of Profit hybrid packed in recyclable bag and stored for 1 and 3 months under ambient conditions followed by two months of cold storage (T10 and T12). Even two times sales returned profit seed packed in savegrain bag and stored for 3 months (T30) under ambient conditions followed by two months of cold storage recorded high seed germination of 94%.

CONCLUSION

Fresh and One time sales returned seed of 218+ showed significantly low SMC (11.3 & 11.3%, respectively). But two times sales returned seed of 218+ & Profit hybrids showed significantly high SMC (11.5 & 11.8 %, respectively). Seed of 218+ and Profit packed in Savegrain (P2), Polypouch (P1) and Triple layer bag (P3) recorded significantly lower pooled mean SMC (11.2, 11.3 & 11.3 %) compared to Recyclable (P4) bag (11.6 & 11.4 %, respectively). Fresh and One time sales returned seed of 218+ hybrid showed significantly high seed germination (95 & 95%, respectively) compared to two times sales returned seed (53%). But, no significant differences were observed among seed lots of Profit. Seed of 218+ packed in Savegrain (P2), Polypouch (P1) and Triple layer bag (P3) recorded significantly higher pooled mean seed germination (82, 81 & 81 %, respectively) when compared to Recyclable bag (80%). But, packing material recorded no significant influence on seed germination in Profit. Seed of 218+, stored for one month at retailer showed significantly higher pooled mean SG (83 %) compared to two and three months (80 and 79 %, respectively) whereas Profit seed recorded significantly high seed germination (92%) even after 3 months of storage at retailer. This indicates that 3 months of ambient storage followed by 2 months of cold storage retained good seed germination in profit but not in 218+ hybrid.

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Research Article
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CHARACTERISATION OF CALCAREOUS SOILS IN RANGAREDDY DISTRICT OF TELANGANA STATE

MERAJ SIDDIQUA[1], S. HARISH KUMAR SHARMA[1], M. SHANKARIAH[1], S. TRIVENI[2] and D. SRINIVASA CHARY[3]

[1]Department of Soil Science & Agricultural Chemistry, College of Agriculture, Rajendranagar

[2]Department of Microbiology and Bio energy, College of Agriculture, Rajendranagar

[3]Department of Mathematics and Agricultural Statistics, College of Agriculture, Rajendranagar

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ABSTRACT

A survey was conducted in the year 2019-20 in old Rangareddy district of Telangana state to study the characters of calcareous soils, based on effervescence with dil.HCL the samples were collected and were analysed for its characters. Majority of soils collected were medium to high in $CaCO_3$ status. All the soils collected were alkaline to highly alkaline in reaction. Soils were low to medium in available nitrogen and phosphorus content. The average pH, available N, available P_2O_5, available K_2O value recorded in these soils were 8.49, 77.19 Kg ha^{-1}, 6.215 Kg ha^{-1}, 72.88 Kg ha^{-1} respectively. Correlation study reported that there is significant positive relationship is seen between $CaCO_3$ content and pH and significant negative relationship is seen between $CaCO_3$ content and available N and P_2O_5 in soil. No significant relationship is seen between $CaCO_3$ content and EC and OC values and significant positive relationship is seen with available K.

Key words: *Calcareous Soil, characterization, $CaCO_3$ Content, Correlation.*

Calcareous soils are soils rich of calcium carbonate which occur mainly in the arid and semi-arid subtropics of both hemispheres. The diagnostic horizon in the calcareous soil is the calcic horizon which contains more than 15% $CaCO_3$ and has a depth of more than 15cm thick. Potential productivity of calcareous soils is relatively high where adequate water and nutrients can be supplied. Crusting of the surface may affect not only infiltration and soil aeration but also the emergence of seedlings. Cemented conditions of the subsoil layers may hamper root development and water movement characteristics.

Many scientists discussed the definition of Calcareous soils as soils which contains high levels of calcium carbonate ($CaCO_3$) that affects soil properties related to plant growth, such as soil water relations and the availability of plant nutrients. Calcareous soils are common in the arid areas of the earth (FAO, 2016) occupying >30% of the earth's surface, and their $CaCO_3$ content varies from just detectable up to 95% (Marschner, 1995). Calcareous soils are the soils in which a high amount of calcium carbonate dominates the problems related to agricultural land use. They are characterized by the presence of calcium carbonate in the parent material and by a calcic horizon, a layer of secondary accumulation of carbonates (usually Ca or Mg) in excess of 15% calcium carbonate equivalent and at least 5% more carbonate than an underlying layer. In the World Reference Base (WRB) soil classification system calcareous soils may mainly occur in the Reference Soil Group of *Calcisols.*

Calcareous soils are common in arid and semi-arid climates affecting over 1.5 billon acres of land worldwide. These soils are identified on the basis of presence of the mineral calcium carbonate in the parent material and an accumulation of lime. Calcite and aragonite ($CaCO_3$), dolomite [$CaMg(CO_3)_2$] and Magnesite ($MgCO_3$) are the calcium and magnesium carbonate minerals found in calcareous soils. They are mainly present as calcite, and to a lesser extent as dolomite. It is most easily recognized by the effervescence or fizz that occurs when these soils are treated with dilute acid (Agriculture Canada, 1976 and Soil Science Society of America, 1997). The pH of these soils is usually above 7.0 and may be as high as 8.5 (Yaalon, 1957). When such soils contain sodium carbonate, the pH may exceed 9.0. Calcareous soils are classified in to four classes based on the presence of calcium carbonate percent in them and they are slight

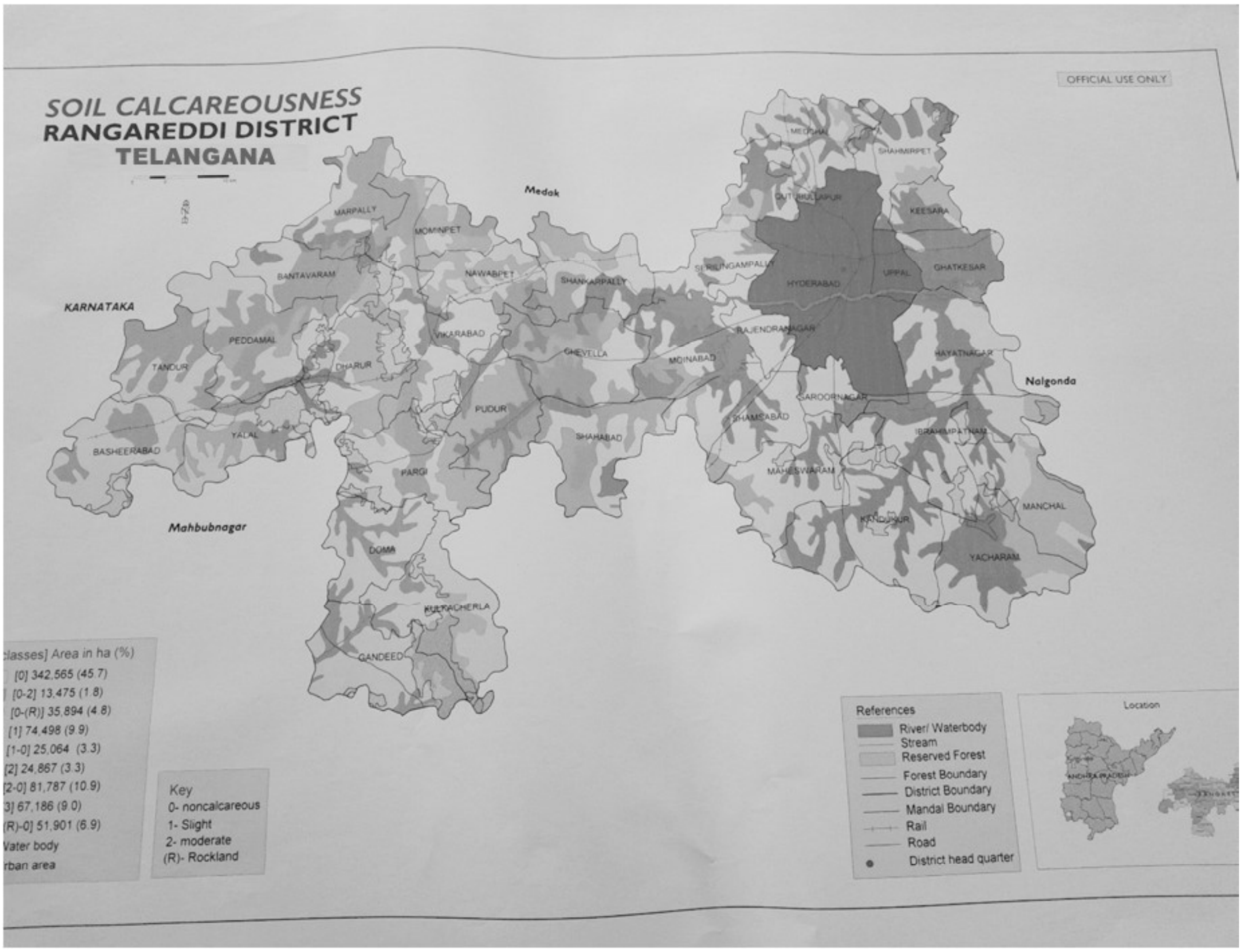
Email: merajsiddiqua@yahoo.com

(0-5%), moderate (5-10%), high (10-20%) and very high calcareous soils (20- 25%) by Kulkarni *et al.,* 2019. Calcareous soils are productive for agricultural use when they are managed properly.

MATERIAL AND METHODS

The survey work was conducted during 2019-2020 to collect representative surface soil samples of different calcareous soils in old Rangareddy district of Telangana state. On the field dil.HCl was applied with the help of dropper, the soils which has effervescence were subjected to chemical analysis and categorized into slightly, moderately and strongly calcareous soils with respect to per cent calcium carbonate status.

Ranga reddy District is located in the Central Part of the Deccan Plateau and area is 5,031 Sq Km. The district was situated between 77° 30' and 79° 30’E, of the eastern longitudes and 16° 30' and 18° 20’N, of northern latitudes. The boundaries of Rangareddy district are Nalgonda district, Mahabubnagar district, Karnataka state and Medak district in the East, South, West and North directions respectively.



NBSSLUP, 2004

Soil sample collection and chemical analysis

The collected samples were air-dried, ground and passed through a 2 mm sieve and stored in polythene bags for further analytical work. The pH and EC of soils was measured in 1:2.5 soil water suspension using a glass electrode and Conductivity Bridge, respectively (Jackson, 1973). The organic carbon content of the soil was estimated by Walkley and Black’s wet oxidation method as described by Jackson, 1973. Calcium carbonate in soil was determined $CaCO_3$ contents will be estimated by titrimetric method. (soil is allowed to react with excess of HCl and unused acid is back titrated with NaOH). The available nitrogen was determined by alkaline

Table 1. Properties of calcareous soil samples collected from Rangareddy district

S. No.	Village	Mandal	%CaCO3	pH	EC	OC%	N (Kg ha^{-1})	P_2O_5 (Kg ha^{-1})	K_2O (Kg ha^{-1})
1	Kummera	Chevella	11.82	8.85	0.44	0.44	156.70	14.90	396.49
2	Dharmasagar	Chevella	12.25	8.89	1.71	0.77	152.90	14.60	393.49
3	Narketpally	Chevella	12.93	8.96	0.17	0.58	145.40	14.30	390.49
4	Kummera	Chevella	11.76	8.85	0.66	0.36	157.60	14.90	389.49
5	Mithakodu	Pargi	5.48	8.00	0.53	1.21	367.90	31.80	389.00
6	Nazeebper	Moinabad	6.52	8.20	0.56	0.39	300.90	25.90	388.00
7	Devarampally	Moinabad	8.51	8.46	0.44	1.21	199.50	19.90	385.60
8	Pulamidi	Nawabpet	8.12	8.42	2.81	0.45	201.90	20.60	383.60
9	Maddireddypally	Nawabpet	8.47	8.46	0.36	0.80	200.30	20.40	380.60
10	Chittigidda	Nawabpet	8.96	8.51	0.28	0.44	194.80	19.30	377.60
11	Datapur	Nawabpet	8.33	8.44	1.30	0.89	200.60	20.50	345.60
12	Pulamidi	Nawabpet	4.76	7.83	0.64	0.66	480.00	41.60	345.00
13	Kasaram	Shamshabad	11.47	8.80	2.09	0.58	160.90	15.60	344.20
14	Peddatur	Shamshabad	11.94	8.85	0.15	0.55	155.20	14.80	341.49
15	Maharajpet	Shamshabad	8.01	8.40	0.46	1.18	205.00	20.80	340.60
16	Narkhuda	Shamshabad	9.22	8.55	2.38	0.69	189.90	18.80	340.60
17	Malkaram	Shamshabad	9.76	8.61	1.11	0.61	185.70	18.40	340.60
18	Jukal	Shamshabad	11.08	8.75	0.33	1.01	169.00	16.10	340.20
19	Gandiguda	Shamshabad	6.90	8.23	2.91	0.69	231.80	24.40	338.00
20	Janwed	Shamshabad	5.41	8.00	0.54	0.68	370.50	33.30	336.00
21	Kaveli	Shamshabad	10.12	8.63	0.16	0.90	184.00	17.60	333.60
22	Donthepally	Shamshabad	4.84	7.84	0.93	0.62	475.00	39.50	333.00
23	Miryalaguda	Shamshabad	13.36	9.00	1.70	0.27	143.00	13.60	332.49
24	Gopularam	Shamshabad	11.65	8.85	0.94	0.26	158.10	14.90	369.49
25	Maharajpet	Shamshabad	7.70	8.34	0.73	0.37	208.20	21.40	365.60
26	Piligundla	Shamshabad	5.93	8.10	1.22	0.67	341.30	28.70	365.00
27	Poddatu	Shamshabad	5.70	8.04	0.58	1.30	364.00	31.50	363.00
28	Jukal	Shamshabad	5.90	8.10	4.39	0.56	342.90	29.30	360.00
29	Ghansimiyan-guda	Shamshabad	9.71	8.61	1.31	0.65	185.70	18.50	358.60
30	Burjiguda	Shamshabad	11.98	8.87	0.73	0.68	154.80	14.80	358.49
31	Malkaram	Shamshabad	6.52	8.19	0.79	0.45	310.00	26.10	357.00
32	Donthapally	Shamshabad	8.05	8.40	0.81	1.20	204.30	20.80	356.60
33	Sultanpalle	Shamshabad	5.49	8.01	0.20	1.39	367.00	31.60	356.00
34	Narkhuda	Shamshabad	7.71	8.35	0.58	0.66	208.20	21.20	353.60
35	Chittampally	Vikarabad	11.65	8.84	0.71	0.76	159.00	14.90	353.49

S. No.	Village	Mandal	%CaCO3	pH	EC	OC%	N (Kg ha^{-1})	P_2O_5 (Kg ha^{-1})	K_2O (Kg ha^{-1})
36	Pacharigedda	Vikarabad	11.58	8.83	1.46	0.36	159.90	15.20	219.20
37	Ramangapuram	Vikarabad	10.22	8.65	1.18	0.80	181.80	17.30	218.60
38	Pacharigedda	Vikarabad	6.19	8.12	1.59	0.45	316.30	27.50	218.00
39	Salkanurlu	Vikarabad	10.93	8.74	0.25	0.35	172.80	16.50	214.20
40	Ravulapenta	Vikarabad	10.29	8.65	0.26	0.63	180.20	16.90	213.60
41	Gottimukle	Vikarabad	5.70	8.05	1.39	1.33	352.60	31.50	213.00
42	Moulkapatnam	Vikarabad	7.92	8.35	0.24	0.76	205.60	20.90	210.60
43	Chittampally	Vikarabad	4.90	7.85	0.20	0.87	440.00	37.70	210.00
44	Pottur	Vikarabad	8.55	8.48	0.95	0.34	199.10	19.80	209.60
45	Shivareddypet	Vikarabad	7.41	8.30	1.82	0.36	214.20	22.80	208.00
46	Cheemaladari	Mominpet	10.04	8.62	0.33	0.40	185.60	18.40	207.60
47	Devarampally	Mominpet	6.52	8.20	2.14	0.46	289.20	25.70	207.00
48	Momimpet	Mominpet	12.51	8.93	2.72	0.69	149.20	14.50	205.49
49	Bokaram	Mominpet	6.52	8.20	0.85	0.67	289.40	25.70	205.00
50	Chakrampalle	Mominpet	12.93	8.95	0.04	1.19	147.00	14.30	201.49
51	Burugapalle	Mominpet	10.05	8.63	0.34	0.69	184.40	17.90	169.60
52	Yenkepalle	Pudur	10.40	8.69	0.40	0.40	179.00	16.90	169.60
53	Kothapalle	Pudur	6.52	8.18	0.53	0.55	310.00	26.30	168.00
54	Pudur	Pudur	6.59	8.20	0.61	0.98	264.00	25.10	168.00
55	Thirmalapur	Pudur	7.08	8.24	0.26	0.49	218.20	23.70	168.00
56	Kervelli	Pudur	6.68	8.20	1.83	0.86	263.70	24.80	167.00
57	Umenthal	Pudur	7.20	8.26	0.34	0.53	214.60	23.20	167.00
58	Siriyampally	Pudur	6.40	8.16	1.07	0.35	314.00	26.80	165.00
59	Ramkamchera	Pudur	8.87	8.51	0.84	0.49	195.70	19.50	163.60
60	Rangampall e	Pargi	12.08	8.87	1.49	0.46	153.30	14.70	162.49
61	Govindapur	Pargi	14.03	9.05	0.60	0.28	138.80	13.10	160.49
62	Lakhanapur	Pargi	6.82	8.22	1.95	0.78	240.20	24.80	160.00
63	Mittakodur	Pargi	9.51	8.60	0.34	0.86	188.10	18.50	158.60
64	Sultanpur	Pargi	6.54	8.20	0.85	0.77	287.90	25.40	158.00
65	Pargi	Pargi	6.05	8.12	0.45	0.56	325.90	27.90	155.00
66	Chigurlapally	Pargi	6.25	8.15	1.31	1.53	314.50	27.00	153.00
67	Narkal	Pargi	7.14	8.25	0.30	0.67	215.20	23.50	150.00
68	Lakhnapur	Pargi	8.07	8.40	0.51	0.76	204.00	20.80	279.60
69	Tandur	Tandur	12.32	8.89	0.30	0.28	151.80	14.60	278.49
70	Rampur	Tandur	6.10	8.12	1.38	0.66	324.80	27.80	278.00
71	Konapur	Tandur	10.40	8.69	0.43	0.31	179.00	16.90	276.60
72	Goutapur	Tandur	7.90	8.35	0.47	0.65	206.60	20.90	273.60

S. No.	Village	Mandal	%CaCO3	pH	EC	OC%	N (Kg ha^{-1})	P_2O_5 (Kg ha^{-1})	K_2O (Kg ha^{-1})
73	Bennur	Yelal	10.04	8.62	2.32	0.37	185.50	18.30	273.60
74	Yelal	Yelal	11.09	8.75	0.46	1.21	168.90	16.10	273.20
75	Agnoor	Yelal	6.79	8.20	0.43	0.37	241.50	24.80	270.00
76	Jakkepalle	Yelal	7.87	8.35	0.35	0.79	207.80	20.90	268.60
77	Hajipur	Yelal	12.47	8.90	0.81	0.36	149.50	14.50	268.49
78	Panchalingal	Marpalle	7.41	8.28	1.92	0.83	214.40	22.80	268.00
79	Patloor	Marpalle	7.44	8.30	0.27	0.67	213.10	22.70	268.00
80	Marpalle	Marpalle	10.94	8.75	0.56	0.55	172.80	16.50	267.20
81	Buchanpalle	Marpalle	8.55	8.46	0.20	0.68	199.10	19.80	265.60
82	Damasthapur	Marpalle	5.88	8.10	0.29	0.73	348.00	29.80	265.00
83	Somaram	Bantwaram	5.82	8.09	1.83	0.58	350.00	29.90	325.00
84	Yacharam	Bantwaram	11.77	8.85	0.44	0.30	156.80	14.90	322.49
85	Noorullapur	Bantwaram	10.98	8.75	0.20	1.01	171.70	16.20	320.20
86	Bantwaram	Bantwaram	5.41	8.00	0.68	0.64	375.40	33.80	320.00
87	Rompalle	Bantwaram	6.55	8.20	0.64	1.12	266.50	25.10	320.00
88	Kerelly	Dharoor	6.94	8.23	2.85	0.78	231.00	24.30	320.00
89	Ebbanoor	Dharoor	9.22	8.55	0.93	0.47	191.50	18.90	319.60
90	Allipur	Dharoor	9.01	8.54	2.39	0.38	194.10	19.00	318.60
91	Rudraram	Dharoor	10.29	8.65	0.33	0.44	180.60	17.10	318.60
92	Ousapalle	Dharoor	10.72	8.69	1.15	0.38	178.00	16.80	318.60
93	Janwed	Shankarpally	10.76	8.70	0.40	0.80	176.50	16.70	317.20
94	Shimmareddy-gudem	Shankarpally	11.62	8.83	0.39	0.78	159.00	15.00	316.49
95	Bhulkapur	Shankarpally	13.86	9.00	0.46	0.43	141.40	13.50	316.49
96	Masaniguda	Shankarpally	11.43	8.77	0.09	0.27	166.40	15.80	309.20
97	Gopularam	Shankarpally	5.79	8.07	1.46	0.56	350.40	30.70	308.00
98	Mahalingapuram	Shankarpally	10.98	8.75	0.41	0.59	172.80	16.30	304.20
99	Kondakal	Shankarpally	7.97	8.37	0.69	0.67	205.40	20.80	303.60
100	Chandippa	Shankarpally	9.36	8.58	0.43	1.41	189.40	18.70	303.60
101	Anthappaguda	Shankarpally	13.86	9.00	0.72	0.67	140.60	13.50	303.49
102	Fathepura	Shankarpally	10.12	8.64	1.36	0.51	182.80	17.50	302.60
103	Tangutooru	Shankarpally	8.47	8.45	0.78	0.43	200.30	20.40	300.60
104	Annojiguda	Kandukur	8.98	8.54	0.25	0.68	194.30	19.30	408.60
105	Gafoornagar	Kandukur	12.32	8.89	0.25	1.23	151.90	14.60	398.49
106	Jaithwaram	Kandukur	8.09	8.42	1.83	0.56	203.30	20.70	376.60
107	Bachupalle	Kandukur	11.05	8.75	0.07	1.30	169.30	16.20	373.20
108	Mohammadnagar	Kandukur	14.11	9.05	0.46	0.57	135.90	12.90	371.49

S. No.	Village	Mandal	%CaCO3	pH	EC	OC%	N (Kg ha^{-1})	P_2O_5 (Kg ha^{-1})	K_2O (Kg ha^{-1})
109	Peruguguda	Kandukur	13.52	9.00	1.01	0.86	142.70	13.60	353.49
110	Murlinagar	Kandukur	14.28	9.07	0.56	0.76	135.70	12.90	353.49
111	Nednur	Kandukur	11.47	8.80	1.00	0.34	160.50	15.60	349.20
112	Timmapur	Kandukur	11.11	8.75	1.26	1.24	168.00	15.90	347.20
113	Lemoor	Kandukur	14.43	9.11	0.11	0.67	131.70	12.40	346.49
114	Bogaram	Keesara	13.08	8.99	1.35	1.06	144.40	14.00	331.49
115	Cheeriyal	Keesara	10.76	8.70	0.80	0.53	176.80	16.80	329.20
116	Dharmavarm	Keesara	7.90	8.35	0.94	0.55	206.90	20.90	259.60
117	Godmakunta	Keesara	5.47	8.00	0.32	2.10	368.60	32.90	259.00
118	Haridaspalla	Keesara	10.19	8.64	0.40	0.76	182.70	17.40	258.60
119	Keesara	Keesara	7.62	8.34	0.27	0.88	210.70	21.80	256.00
120	Kundanpalle	Keesara	8.62	8.48	1.24	1.00	197.80	19.60	255.60
121	Narsampalle	Keesara	5.04	7.95	0.25	0.67	395.00	35.40	253.00
122	Thimmaiplle	Keesara	7.05	8.24	0.92	0.13	218.90	23.80	253.00
123	Yadgarplle	Keesara	12.47	8.90	1.19	0.48	149.20	14.50	251.49
124	Dammiguda	Medchal	7.94	8.36	0.57	1.34	205.60	20.90	250.60
125	Farzanguda	Medchal	7.16	8.25	1.48	1.85	214.90	23.40	282.00
	Mean		9.08	8.50	0.88	0.70	220.28	20.85	288.86
	SD		2.58	0.32	0.74	0.34	77.20	6.22	72.66

potassium permanganate method given by Subbiah and Asija (1956) and Available phosphorus in soil was extracted by Olsen's extractant as described by Olsen *et al.* (1954) and Available potassium were extracted with neutral normal ammonium acetate solution and using flame photometer (Jackson, 1973).

RESULTS AND DISCUSSION

Characters of different samples calcareous soils is given in Table 1.

The percent of calcium carbonate in the soil samples collected from Rangareddy district ranged from 4.76 (lowest) to 14.43 (highest). The $CaCO_3$ content variation in these soils may be due to parent material, native $CaCO_3$ content in soil profile and faulty agricultural practices. Similar reports regarding the presence of calcium carbonate content in vertisols were reported by Halajinia *et al.* (2009). According to categorisation 16 soil samples collected are slight calcareous, 57 are moderately calcareous and remaining 53 were highly calcareous, mean value for $CaCO_3$ content is 9.1. All calcareous soils were alkaline in nature with pH value ranging from 7.13 to 9.11 with the average value of 8.5. Being predominated by calcium carbonate, it was logical that pH of these soils were alkaline. Similar analytical result for soil pH in calcareous soils was reported by Afif *et al.* (1993). Organic carbon percent for these soils remained low to medium 0.13 to 1.85 percent due to insufficient availability of organic manures. The average OC value is 0.703 %.

The highest available nitrogen content in soils was 482 kg ha^{-1} and 131.5 kg ha^{-1} being the lowest value with the average value of 77.2 kg ha^{-1}, majority of the soils were belongs to category of low to medium in available nitrogen. The poor status of soil organic carbon resulted in low status of available nitrogen. The available phosphorus ranged 12.4 to 41.6 kg ha^{-1} with average value of 6.22 kg ha^{-1} from implies that majority of the soils were low to medium in available phosphorus. It may be due to phosphorus fixation as Ca-P in soil resulted in low status of phosphorus. Similar result of low availability of phosphorus in

Table 2. Correlation among the different properties of calcareous soils

	$CaCO_3$	pH	EC	OC	avail N	avail P	avail K
$CaCO_3$	1.000						
pH	0.994 **	1.000					
EC	-0.146 NS	-0.130 NS	1.000				
OC	-0.212 *	-0.219 *	-0.124 NS	1.000			
N	-0.863 **	-0.899 **	0.085 NS	0.205 *	1.000		
P	-0.924 **	-0.954 **	0.103 NS	0.221 *	0.981 **	1.000	
K	0.205 *	0.203 *	0.034 NS	0.059 NS	-0.113 NS	-0.143 NS	1.000

calcareous soils was reported by Mostashari *et al.*, 2008. Maximum available potassium recorded was 408.4kg ha^{-1}; minimum available potassium recorded was 130.1 average of 72.88 kg ha^{-1}.

The correlation analysis indicated significant positive relationship between $CaCO_3$ content and pH values. As the $CaCO_3$ value increases there is increase in pH value is observed. This is because of the dissolution of excess $CaCO_3$ present in these soils, results in a high solution HCO_3^- concentration, that buffers the soil in the pH range of 7.5 to 8.5 (Imas, 2000): as $CaCO_3$ + H_2O"! Ca^{2+} + HCO_3^- + OH^-.

There is significant negative relationship is seen between $CaCO_3$ content and available nitrogen and available P, because as the $CaCO_3$ content increases, the pH value will also increase (Table 2). The alkaline pH values affects the rates of N transformations, which in turn can influence the efficiency of N use by plants (Wahba *et al.,* 2019) and at higher pH values, phosphate anions react with Ca and Mg to form phosphate compounds of limited solubility reported by Mortedt (1999). Maximum availability to plants of both native and applied P is in the pH range of 6.0 to 7.5. there is no significant relationship is seen between EC, OC and available K.

CONCLUSION

Majority of the soil samples collected were medium to high in calcium carbonate content. All of the samples collected (Slightly, moderately and strongly calcareous soils) were alkaline in reaction. These soils were slightly saline to saline and organic carbon status of these calcareous soils remained low to medium. Different type of calcareous soils belongs to low to medium in available nutrients *i.e.,* N, P, K content. Slightly calcareous soils had relatively more available nutrients (N, P, K,) compare to moderately and strongly calcareous soils. OC and EC values remained unaffected by $CaCO_3$ content.

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SOIL FERTILITY STATUS OF PADDY GROWING RED SOILS OF CENTRAL TELANGANA ZONE DISTRICTS OF TELANGANA STATE, INDIA

D. RAJASHEKHAR[1], A. MADHAVI[2], P. SURENDRA BABU[3], T RAMPRAKASH[4], K. P. VANI[5] and D. SRINIVASA CHARY[6]

[1]Department of Soil Science & Agricultural Chemistry, College of Agriculture, Rajendranagar
[2]Institute of Soil Health Management, AICRP-STCR, Rajendranagar
[3]Institute of Soil Health Management, AICRP on Micronutrients, Rajendranagar
[4]AICRP - Weed Management, Diamond Jublee Block, Rajendranagar
[5]Department of Agronomy, Agricultural College, Sircilla
[6]Department of Statistics and Mathematics, College of Agriculture, Rajendranagar, Hyderabad

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ABSTRACT

Soil fertility evaluation of an area is an important aspect in context of sustainable agriculture production. The macronutrients regulate soil fertility and control crop growth and yields. In this inquiry, the Central Telangana Zone (CTZ) in the State of Telangana was chosen, and the availability of macronutrients and their relationship to physico-chemical characteristics in red soils were explored. Forty five red soil predominated *mandals* were chosen and 59 surface soil (0-15 cm) samples collected from red soil predominated *mandals* and analyzed for physico-chemical properties and available N, P and K status using standard laboratory procedures. The value of pH, electrical conductivity, and organic carbon was ranged from 6.65 to 7.78, 0.02 to 0.72 dS m^{-1} and 0.19 to 0.51% respectively. The available N, P_2O_5 and K_2O was ranged from 50 to 314, 17 to 147 and 72 to 627 kg ha^{-1}, respectively. The available nitrogen was in low, phosphorus and potassium contents were in high. Available micronutrients iron and zinc was ranged from 0.58 to 5.92 and 0.06 to 4.81 mg kg^{-1}, respectively. Out of 59 collected soil samples, 97% were low in available nitrogen, 90% and 47% were high in available phosphorus and potassium respectively.

Key words: soil physico-chemical properties; macro nutrient status, micronutrient status

Soil contains large amount of nutrient reserves in them but all or part of reserves may not be used by the crop because they may not be present in plant available form (FAO 2008). According to (Barker and Pilbeam 2007) plant nutrition lies in use of diagnostic techniques for assessment of soil status with respect to plant nutrients. Intensive agricultural practices without balanced use of chemical fertilizers, excessive tillage practices, no use of organic manures caused deterioration of agricultural soils thereby declining the soil health and crop productivity (Bhupen *et al.*, 2013). Among the techniques of the fertility evaluation such as plant analysis, soil analysis; soil test will provide accurate information on plant available nutrients (Singh *et al.*, 2017). Nitrogen is required for the plant growth and it a major constituent of chlorophyll, plant protein and nucleic acid. Phosphorus is a limiting nutrient in the soil which goes for fixation. It act as an energy storage and plays a major role in root development. It is known that over 60 enzymes need potassium for their activity. It plays major role in disease resistance, stomata regulation, ionic and osmatic balance (Swanti *et al.*, 2014). Whereas soil physical properties provide information on air and water movement through soils since many physical properties form foundation for biological and chemical processes (Varsha *et al.*, 2018). The present work deals with physico-chemical and chemical properties analysis of rice growing red soils in Central Telangana Zone districts, Telangana.

MATERIAL AND METHODS

Description of study area

The zone comprises of the districts of Sangareddy, Medak, Siddipet, Jangaon, Warangal Urban, Warangal Rural, Mahabubabad, Jayashankar Bhupalapally, Bhadradri Kothagudem and Khammam districts. The zone covers an area of 3.86 m. ha. The soils of the zone are mainly red sandy loams, very red soils and deep black soils. The zone receives an annual normal rainfall of 996 (868-1124) mm. About 88.03 per cent of total rainfall is received during south west monsoon only. The net sown area is l.25 m. ha.

Email: rajashekardandu@gmail.com

of which 0.51 m. ha. is irrigated representing 40.68 per cent of the net sown area. The principal crops grown in the zone are Paddy, Cotton, Red gram, Maize, Sugarcane, Black gram and Green gram.

The top 10 rice crop acreage *mandals* in each district of Central Telangana zone of state were chosen based on five years acreage of rice crop of *kharif* and *rabi* seasons prior to soil sample collection years of 2018-19 and 2019-20. Central Telangana zone comprised of ten districts and thus a 10 *mandals* in each district, totaling 100 *mandals* in entire Central Telangana zone of state. With the aid of soil map of NBSSLUP, Nagpur, red soil type *mandals* (n=45) from these 100 *mandals* were separated and grouped as red soil predominated *mandals* of Central Telangana Zone.

Soil sampling and characterization

Red surface soils (0-15cm) samples were collected from representative *mandal* locations of CTZ where paddy crop was growing for analyzing their physico-chemical properties and available status of major nutrients. The collected soil samples were air-dried under shade and then, 250 g of soil from above bulk samples was ground using wooden mortar and pestle and passed through a 2 mm sieve and preserved in labeled bags for laboratory analysis.

In this study, soil pH was determined in 1:2.5 soil water suspension by using pH meter with glass electrode (Model Elico LI 127) (Jackson, 1973). The electrical conductivity was determined in 1:2.5 soil water suspension with help of a digital conductivity meter (Model Elico CM 180) (Jackson, 1973). Organic carbon of dry soil samples was determined by the Walkley–Black method (Walkly and Black 1934). The available nitrogen was estimated by the alkaline potassium permanganate method by Subbiah and Asija (1956). Available phosphorus in the soils was extracted by Olsen's extractant method as described by Olsen *et al.* (1954) and phosphorus in the extract was determined by using ascorbic acid as reducing agent as outlined by Watanabe and Olsen (1965) using colorimeter (Model ECIL GS 5701 SS) at 660 nm wavelength. Available potassium in the soil was extracted by using neutral normal ammonium acetate method (Jackson, 1973) and determined by aspirating the extract into the flame photometer (Model Elico CL 361).

RESULTS AND DISCUSSION

Fifty nine soil samples were collected from paddy cultivated fields of forty five red soil predominant *mandal*s in central agro climatic zone of Telangana state. Care was taken to collect samples from the red soil mapped unit area of NBSSLUP map and also through field observations on the ground.

The results of the analysis of samples collected from paddy grown red soil fields in different districts of Central agroclimatic zone of Telangana State showed that most of the fields were low in organic C, high in extractable (available) P, but generally adequate in extractable K (Table 2). On the basis of the nutrient ratings suggested by Muhr *et al.* (1965) in the soil used for categorizing soils into low, medium and high for (extractable) N, P_2O_5 and K_2O are given in Table 1.

Table 1. Nutrient rating limits of soil (Muhr *et al.*, 1965)

	OC (%)	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
Low	0.5	280	25	145
Medium	0.5-0.75	280-560	25-59	145-340
High	0.75	560	59	340

pH, EC and OC (%) :

The samples had a range of 6.65-7.78 in pH. The electrical conductivity ranged from 0.02 to 0.719 with a mean of 0.262 dSm^{-1}. The results indicated that the majority of soils were neutral in nature and suitable for all types of crops and similar results were reported by Shinde and Patil (2016) at Agriculture College farm, Nandurbar, and Rajamani *et al.* (2020) at KVK, Palem. The organic carbon of red soils in central agro-climatic zone was ranged from 0.19 to 0.51% with a mean of 0.40%. Fifty samples constituting 85 per cent among these samples were registered low in organic carbon status and 14 per cent in medium status.

Table 2. Physico-chemical, major and micro nutrient status of paddy supporting red soils of Central agro-climatic zone of Telangana State

Districts	No.of samples		pH	EC	OC	Available Nutrients				
						N	P_2O_5	K_2O	Fe	Zn
				(dSm^{-1})	(%)	(kg ha^{-1})			(mg kg^{-1})	
Khammam	5	Range	6.71-7.60	0.10-0.50	0.25-0.46	188-276	57-105	235-396	26.4-37.8	0.52-0.92
		Mean	7.20	0.30	0.33	223.48	78.96	329.18	34.42	0.68
Bhadradri	6	Range	6.68-7.54	0.19-0.56	0.34-1.09	113-314	77-136	250-420	24.0-36.4	0.61-2.18
		Mean	7.18	0.35	0.65	248.79	111.17	341.21	28.13	1.22
Mahabubabad	6	Range	6.65-7.69	0.02-0.35	0.25-0.74	48-147	134-487	10.9-25.7	0.24-1.17	0
		Mean	7.32	0.17	0.47	99.17	323.48	18.50	0.60	0.00
Warangal Rural	2	Range	7.21-7.26	0.183-0.420	0.22-0.41	100-101	65-77	419-446	11.7-17.8	1.55-3.45
		Mean	7.23	0.30	0.32	100.44	71.01	432.00	14.75	2.50
Jayashankar Bhoopalpally	4	Range	7.11-7.52	0.13-0.72	0.19-0.40	63-113	70-105	337-450	15.5-32.9	0.50-2.41
		Mean	7.26	0.35	0.27	81.54	84.22	384.56	27.66	1.10
Warangal Urban	5	Range	6.83-7.37	0.15-0.31	0.19-0.57	63-176	90-117	117-349	4.9-38.4	0.33-2.42
		Mean	7.12	0.23	0.32	123.47	105.58	263.13	16.41	1.23
Janagaon	15	Range	6.65-7.78	0.12-0.66	0.21-0.50	89-226	73-117	72-627	16.4-40.7	0.31-1.88
		Mean	7.21	0.26	0.38	135.22	94.70	315.23	27.23	0.90
Siddipet	7	Range	6.68-7.52	0.15-0.43	0.21-0.51	88-213	60-98	194-574	16.4-37.9	0.51-3.63
		Mean	7.18	0.28	0.35	158.55	81.11	339.29	29.64	1.41
Medak	6	Range	6.91-7367	0.17-0.33	0.31-0.56	126-226	17-110	169-414	20.8-37.5	0.57-1.59
		Mean	7.26	0.22	0.43	164.94	71.74	270.90	33.40	1.02
Sangareddy	3	Range	6.87-7.34	0.109-0.254	0.29-0.50	101-164	34-96	118-214	6.7-25.3	0.63-0.86
		Mean	7.09	0.20	0.38	134.51	69.70	160.13	13.10	0.74
CTZ (All Districts)	59	Range	6.65 - 7.78	0.02 - 0.719	0.19 - 0.51	50 - 314	17 - 147	72 - 627	4.9-40.7	0.24 - 3.63
		Mean		0.262	0.398	153.233	89.686	314.595	25.98	1.10
		S.D	0.26	0.14	0.16	62.66	25.16	110.75	9.79	0.74
		Low			50	57	1	5	0	17
		%			84.75	96.61	1.69	8.47	0.00	28.81
		Medium			8	2	5	26	0	0
		%			13.56	3.39	8.47	44.07	0.00	0.00
		High			1	0	53	28	59	42
		%			1.69	0.00	89.83	47.46	100.00	71.19

Available major nutrient status (N, P and K)

Most of these soils were low in available nitrogen content across the zone and it is ranged from 50 to 314 kg ha^{-1} with a mean value of 153 kg ha^{-1}. On the basis of the ratings suggested by Muhr *et al.* (1965). Fifty seven samples constituting 97 per cent among these were found to register low available nitrogen of < 280 kg $ha^{-1}$and remaining 3.39% in the category of medium (280 to 560 kg N ha^{-1}). Low nitrogen status in the soils could be due to low amount of organic carbon in the soils and uncertain rainfall has a major impact on availability of nitrogen. Similar results were observed by Singh *et al.* (2015) and Bharteey *et al.* (2017).

The mean available P_2O_5 of red soils supporting paddy crop in the zone was 90 kg ha^{-1} with in a range of 17 to 147 kg ha^{-1}. These soils to an extent of 90 per cent were found to be high in available phosphorus (P >59 kg ha^{-1}). High available phosphorus may be due to fixed phosphorus pool of phosphate contains inorganic phosphate compounds that are very insoluble and organic compounds that are resistant to mineralization by microorganisms in soil. These findings are in agreement with the results reported by Meena *et al.* (2006) in soil of Tonk district of Rajasthan and Bharteey *et al.* (2017).

The available potassium in red soils of supporting paddy in the CTZ ranged from 72 to 627 kg ha^{-1} with a mean of 316 kg K_2O ha^{-1}. Majority of red soils was found to be high in 47.5 per cent of samples (> 340 kg ha^{-1}) followed by medium in 44 per cent and low in 8.5 per cent of samples.

Available Micronutrients (Fe and Zn) Status

The range and mean values of micronutrient status in the paddy supporting red soils of CTZ, Telangana State presented in Table 3. The available Fe status ranged from 4.9 to 40.7 mg kg^{-1} with a mean value of 25.98 mg kg^{-1} indicating an sufficient range of iron status due to occurrence of primary and secondary iron-containing minerals such as hematite, olivine, siderite, goethite, magnetite (Havlin *et al.*, 2010).

The Zn status varied in the range of and 0.24 to 3.63 mg kg^{-1} with a mean of 1.10 mg kg^{-1}. Out of 59 soil samples, about 71% samples were sufficient in available Zn and 29% samples were insufficient status. Similar with the findings of Sellamuthu *et al.* (2015). The conversion of zinc cations to their oxides or hydroxides at higher pH, which is known to have lower solubility, might be the reason for low zinc status.

Correlation of physico-chemical properties and major nutrients of red soils

The data on correlation between soil properties and available nutrients in paddy supporting red soil of Central Telangana zone are presented in Table 3 revealed the pH of the soil is positively non-significantly correlated with nitrogen (r = 0.038), organic carbon (r = 0.105) and negitively non-significantly correlated with phosphorus (r = -0.068) and potassium (r = -0.073). Fernàndez and Hoeft (2012) has critically discussed the availability of plant nutrients under varying pH and suggested that nutrients in soils are strongly affected by soil pH due to reacting with soil colloids and other nutrients. The OC of the soil is positively non-significantly correlated with phosphorus (r = 0.189),

Table 3. Correlation coefficients between soil properties and available soil nutrients

	pH	*EC*	*OC*	*N*	*P_2O_5*	*K_2O*	*Fe*	*Zn*
pH	1							
EC	0.041	1						
OC	0.105	-0.151	1					
N	0.032	0.187	0.419**	1				
P_2O_5	-0.068	-0.008	0.189	0.101	1			
K_2O	-0.073	0.109	0.111	-0.023	-0.014	1		
Fe	-0.003	0.030	-0.024	0.195	-0.278*	0.002	1	
Zn	-0.023	-0.033	-0.183	-0.102	0.020	-0.104	0.081	1

*Significant at 5% level

potassium (r = 0.111) and positively significantly correlated with nitrogen (r = 0.419) Kartikeyan *et al.* (2014) have also reported the similar results in soybean growing soils of Malwa plateau, Madhya Pradesh. The nitrogen of the soil is positively non-significantly correlated with phosphorus (r = 0.101), and negatively non-significantly correlated with potassium (r = -0.023). Similar results reported by Srinidhi *et al.* (2020) who studied on soil fertility status of soils in madanapalle block, Chittor district of Andhra Pradesh. The phosphorous of the soil negatively significantly correlated with iron (-0.278*).

CONCLUSION

It can be concluded that the paddy supporting red soils from Central agro-climatic zone districts are categorized under neutral to slightly alkaline in reaction. Organic carbon is low in these soils of study area. About, 97% of soil samples were in low available nitrogen, available phosphorus found to be high (90%), available potassium also recorded medium (44%) to high (47.5%) status, all soil samples sufficient in Fe and 71% of soil samples in sufficient Zn status.

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Research Article
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IMPACT OF TILLAGE AND RESIDUE MANAGEMENT ON ACID AND ALKALINE PHOSPHATASE ACTIVITIES OF *RABI* MAIZE

CH. RAVALI[1], G. JAYASREE[1], S. TRIVENI[2], K. SAMMI REDDY[3] and G. PRATIBHA[3]
[1]Department of Soil Science, College of Agriculture, PJTSAU, Hyderabad
[2]Department of Microbiology & Bio energy, College of Agriculture, PJTSAU, Hyderabad
[3]Division of NRM, CRIDA, Hyderabad

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ABSTRACT

A field experiment was conducted in college farm, College of Agriculture, Rajendranagar, PJTSAU, Hyderabad, to study different rice residue management options in conservation tillage and conventional tillage in rice-maize cropping system, during *rabi* 2020-21 and 2021-22. There were eight residue management options in each tillage system *viz*., T1- Total removal of residue and RDN (33:33:33), T2 - Residue incorporation/retention + RDN (33:33:33), T3- Residue incorporation/retention + RDN (33:33:33) + Microbial Consortium (2% Spray), T4 - Residue burning + RDN (33:33:33), T5- Residue incorporation/retention + RDN (43:23:33), T6 - Residue incorporation/retention + RDN (43:33:23), T7 - Residue incorporation/retention + 10 % extra RDN (43:23:33), T8 - Residue incorporation/retention + 10 % extra RDN (33:43:23). There were a total of 16 treatments, replicated thrice and laid in strip plot design. The results indicated that tillage and residue management options significantly affected acid and alkaline phosphatase activity as well as available P status in soil. Conservation tillage practice resulted in an increase of acid phosphatase activity by 9 % in *rabi* 2020-2021 and 16 % in *rabi* 2021-2022 over conventional tillage. The increase in the phosphatases activity with residue retention and incorporation led to increase in the available P status of soil during crop growth period till tasseling stage.

Key words: Conservation tillage, Residue incorporation, Acid phosphatase, Alkaline phosphatase, Available P.

Rice - Maize cropping system is one of the major rice based cropping systems in India. In India, Rice - Maize cropping system occupies 0.53 m ha (ICAR-IIRR, 2021). In Telangana, maize was grown in an area of 86,000 ha during *kharif* 2020-21 and 1.73 lakh ha during *rabi* 2020-21, with a production of 399 and 1357 metric tonnes in *kharif* and *rabi* respectively. The productivity of maize in Telangana during *kharif* 2020-21 and *rabi* 2020-21 was 4646 kg ha^{-1} and 7844 kg ha^{-1} respectively (INDIASTAT, 2020-21).

As a response to the worldwide challenge raised by soil degradation, Conservation Agriculture (CA) was proposed to help in restoring the three main soil functions, *i.e.,* carbon transformation, nutrient cycling and structure maintenance. Conservation tillage or minimum soil disturbance is one of the key principles of conservation agriculture. Conservation tillage is defined as any tillage sequence, the objective of which is to minimize or reduce loss of soil and water; operationally, a tillage or tillage and planting combination that leaves a 30% or greater cover of crop residue on the surface. The benefits of conservation tillage are reducing soil erosion, conserving soil moisture, avoiding fluctuations of soil temperature in the arable soil depth and reducing the costs of soil preparation. In addition, the use of conservation tillage is being encouraged as part of a strategy to reduce Carbon loss from agricultural soils. Another important principle of conservation agriculture is crop residue recycling. On an average, rice crop residues contain 0.7% N, 0.23% P and 1.75% K. Therefore, the amount of NPK contained in rice crop residues produced is about 22.13×10^6 and 26.26×10^6 t $year^{-1}$ in Asia and the world, respectively (Goswami *et al*., 2019).

In agricultural systems, P inputs to soils are often required to replenish P removed by harvested crops or lost by soil erosion or runoff. Because soils bind P strongly, historically P inputs have been made more to maintain adequate or high levels of soil fertility and less from a concern that excessive P inputs promote P loss in runoff and erosion. Thus, the challenge for soil P management is to maintain adequate soil P fertility for economical crop production and minimize P loss to the environment. Hence through proper management of crop residues there is a possibility to improve P availability to crop.

Phosphorus (P) is one of the limiting nutrients for plant growth (Turner and Haygarth, 2005). Although organic P makes up approximately 50% of the total P content in most soils, most organic P cannot be directly

Email: ravalireddych96@gmail.com

utilised by crops (Garg and Bahl, 2008). When phosphorus is hydrolyzed into orthophosphate by phosphatases in the soil, it becomes available to plants. The bioavailability of organic P is thus significantly impacted by the phosphatase activity in the soil. Along with phosphomonoesterases (used to hydrolyze organic phosphate monoesters) and phosphodiesterases (used to hydrolyze phosphate diesters), soils also contain pyrophosphatase (which transfers pyrophosphate into orthophosphate). It is currently critical to investigate ways to adopt optimum soil agriculture management to boost soil P storage and the efficiency of P consumption. By influencing the microbial community and P level with an increase in carbon source, straw coverage is a successful residue management technique that regulates the availability of P in soil (Margenot *et al*., 2017). Agricultural practices, such as tillage, cropping systems and crop residue management, have a significant impact on the phosphatase activities in cultivated soil (Zhang *et al*., 2010). Crop residues are heavily deposited on the topsoils in both conservation tillage and straw mulching practices. It in turn increases the surface soil's total P content and phosphatase activity (Redel *et al*., 2007). Both conservation tillage and rice straw incorporation/retention were anticipated to increase plant availability of P, decrease soil P fixation and boost organic P storage and its mineralization through increased phosphatase activities driven by microorganism release.

India imports *90% rock phosphate* from other countries (IBEF, 2021). Fertilizer prices have risen nearly 30% since the start of 2022. Soaring prices are driven by a confluence of factors, including surging input costs, supply disruptions caused by sanctions (Belarus and Russia) and export restrictions (China). Phosphorus fertilizers are typically produced by mining phosphate rock and treating it with sulfuric or phosphoric acid, causing a chemical reaction that converts it to a form that can be absorbed by plants. Therefore, the present study was conducted with the objective to study the impact of tillage and rice residue management options on acid and alkaline phosphatase activities and the availability of soil P at different crop growth stages of maize in two successive years.

MATERIAL AND METHODS

A field experiment was conducted in a sandy clay loam soil, in B block of college farm, College of Agriculture, Rajendranagar, PJTSAU, Hyderabad, to study different rice residue management options in conservation and conventional tillage systems in rice-maize cropping system, during *rabi* 2020-21 and 2021-22. The experiment was laid out in strip plot design. Two levels of factor A (tillage) are assigned to each strip and eight management practices are imposed to each strip, which comes to 16 treatments (8*2) and are replicated thrice. The initial pH of the soil was 8.4, EC was 0.45 dSm^{-1} and available P was 15 kg ha^{-1}. The test crop is maize (DHM 117). The residue burning plots and consortium application plots were demarcated and residue burning and consortium spraying was done in those respective plots. In T1 treatment plots residue was removed upto one inch from the ground. After all these operations, tillage was done in one strip. The details of treatments were given below.

TREATMENT DETAILS

Vertical factor (Tillage)

1. Conventional Tillage 2. Conservation Tillage

Horizontal factor (Residue Management Options):

T1 - Total removal of residue upto 1 inch and RDN (33:33:33)

T2 - Residue incorporation + RDN (33:33:33)

T3 - Residue incorporation + RDN (33:33:33) + Microbial Consortium (2% Spray)

T4 - Residue burning + RDN (33:33:33)

T5 - Residue incorporation + RDN (43:23:33)

T6 - Residue incorporation + RDN (43:33:23)

T7 - Residue incorporation + 10 % Extra RDN (43:23:33)

T8 - Residue incorporation + 10 % Extra RDN (33:43:23)

- **Microbial consortium**: Consists of decomposers belonging to *genera Phanerochaeta, Asperigillus, Trichoderma;* **RDF-** 240-60-60 kg N-P_2O_5-K_2O ha^{-1}

- P and K were uniformly applied to all treatments as basal.

Available phosphorous was extracted by Olsen's extractant (0.5*N* $NaHCO_3$, pH 8.5) described by Olsen *et al.* (1954). The colour development (blue colour) was done by ascorbic acid method given by Watanabe and Olsen (1965).

Phosphatase		Measuredby	Reference
a.	Acid phosphatase	Spectrophotometry	Tabatabai and Bremner (1969)
b.	Alkaline phosphatase	Spectrophotometry	Eivazi and Tabatabai (1977)

The data recorded from the experiment was statistically computed by adopting strip plot design using standard procedures.

RESULTS AND DISCUSSION

Acid phosphatase activity

The data pertaining to effect of tillage and residue management options on acid phosphatase activity at all stages of crop growth was presented in Table 1 and Figure 1. The acid phosphatase activity increased from sowing to tasseling stage and then declined. Results indicated that there was approximately 45 – 53 % increase in activity of acid phosphatase from sowing to tasseling stage in both tillage systems. Maximum acid phosphatase activity was recorded at tasseling stage during both years of experiment. During both years of study, conservation tillage resulted in significantly more acid phosphatase activity than conventional tillage. During 2020-21, the acid phosphatase activity in conservation tillage was 66.83, 91.35, 144.91, 80.47 ìg PNP g^{-1} soil hr^{-1} at sowing, knee high stage, tasseling stage and at harvest respectively. Conservation tillage practice resulted in an increase of acid phosphatase activity by 9 % in *rabi* 2020-2021 and 16 % in *rabi* 2021-2022 over conventional tillage. However, in 2021-22, *i.e.,* during second year of experiment, a little more acid phosphatase activity was recorded throughout crop growth stages.

An increase of 5 to 20% of acid phosphatase was observed in conservation tillage plots during second year of experiment than first year. Wang *et al.* (2011) and Omidi *et al.* (2007) reported that the canola cultivars grown under no tillage recorded significantly higher acid phosphatase activity compared to moderate tillage and conventional tillage. Significantly higher acid phosphatase activity was reported under conservation tillage than conventional tillage (Mullen *et al.*, 2000).

Among residue management options, during *rabi* 2020-21, residue incorporation + microbial consortium + RDN - 33:33:33 (T3) treatment resulted significantly higher acid phosphatase activity (ìg PNP g^{-1} soil hr^{-1}) at sowing (92.51), knee high stage (113.91), tasseling stage (178.07) and at harvest (107.65). Similar trend was observed in 2021-22 as well *i.e.*, higher acid phosphatase activity (ìg PNP g^{-1} soil hr^{-1}) was recorded in T3 treatment (99.99) at sowing which was on par with T7 (95.13) and T8 (96.66). At knee high stage also T3 treatment (119.36) recorded higher acid phosphatase activity which was on par with T7 (110.31 ìg PNP g^{-1} soil hr^{-1}) and T8 (114.25 ìg PNP g^{-1} soil hr^{-1}). At tasseling stage, T3 (180.40 ìg PNP g^{-1} soil hr^{-1}) treatment recorded significantly higher acid phosphatase activity. At harvest, T3 (103.53 ìg PNP g^{-1} soil hr^{-1}), T7 (97.56 ìg PNP g^{-1} soil hr^{-1}) and T8 (100.00 ìg PNP g^{-1} soil hr^{-1}) treatments recorded significantly higher acid phosphatase activity which were on par with each other. The lowest acid phosphatase activity at all the crop growth stages was recorded in residue burning treatment (T4) and control (T1) which are on par. The lower activity of acid phosphatase activity due to burning of residue because of *in situ* crop residue burning leads to the killing of the organisms and hence less production of acid phosphatases (Ravali *et al.*, 2022). During high intensity burning, the temperature reaches 450°C, whereas in moderate and low intensity burning temperature reaches 350°C and 250°C, respectively. Moreover, hydrolytic enzymes are deactivated due to high temperature during burning, thereby reducing soil enzyme activity. However the interaction between tillage and residue management options with respect to acid phosphatase activity was found to be non-significant. Our results were in accordance with Nath *et al.* (2021), who reported that residue retention increased acid phosphatase activity by 31 % over residue removal in legume based cropping system. The phosphatase activity was higher in no tillage with maize residue retention compared to conventional tillage (Yang *et al.*, 2019). The increase in the acid phosphatase activity with age of the crop upto tasseling stage may be due to development of root system with age and increase in total surface area.

The increase in the acid phosphatase activity under no tillage may be due to less soil disturbance,

Table 1. Impact of tillage and residue management options on acid phosphatase activity (ìg PNP g^{-1} soil hr^{-1}) at various growth stages of maize

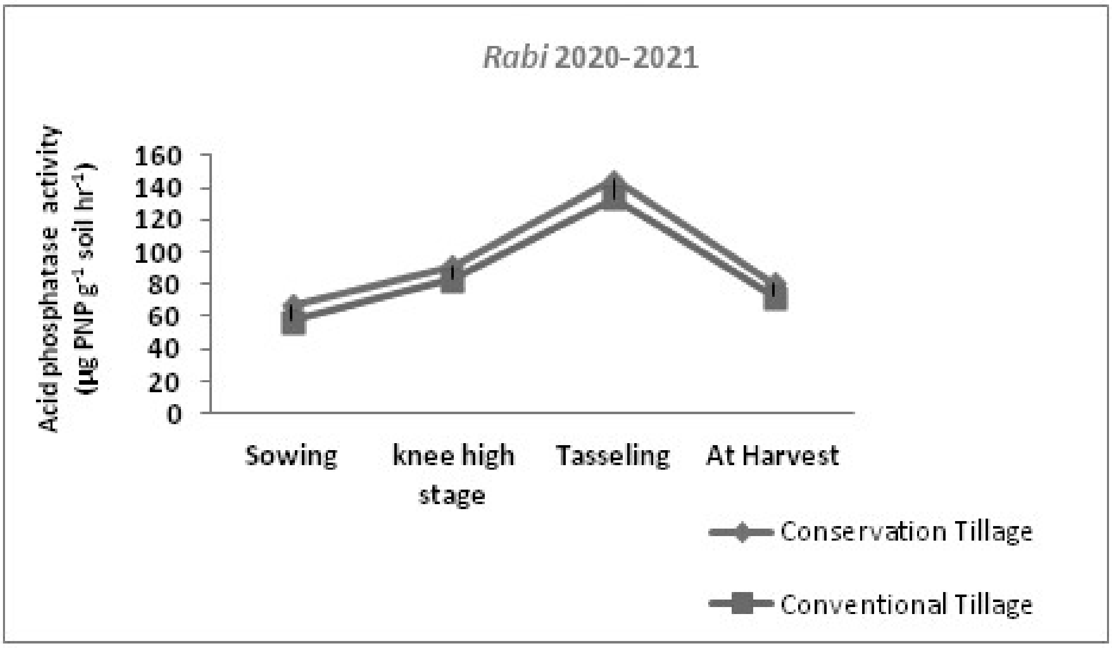
Treatments	Sowing		Knee High Stage		Tasseling Stage		At Harvest	
Tillage								
Year	**2020-2021**	**2021-2022**	**2020-2021**	**2021-2022**	**2020-2021**	**2021-2022**	**2020-2021**	**2021-2022**
Conservation Tillage	66.83 ^{a}	83.84 ^{a}	91.35 ^{a}	99.97 ^{a}	144.91 ^{a}	152.97 ^{a}	80.47 ^{a}	85.13 ^{a}
Conventional Tillage	57.01 ^{b}	61.85 ^{b}	82.86 ^{b}	86.59 ^{b}	133.83 ^{b}	135.13 ^{b}	72.81 ^{b}	72.19 ^{b}
SEM	1.06	1.23	1.34	1.90	1.74	1.19	1.21	1.84
CD 5%	6.45	7.51	8.14	11.58	10.59	7.24	7.33	11.20
Residue management options								
T1	39.32 ^{g}	39.15 ^{f}	59.55 ^{f}	53.63 ^{g}	110.75 ^{g}	88.66 ^{g}	54.98 ^{g}	26.57 ^{g}
T2	61.89 ^{f}	62.89 ^{e}	85.67 ^{e}	95.61 ^{f}	148.38 ^{bcde}	159.26 ^{bcde}	73.83 ^{ef}	88.32 ^{cde}
T3	92.51 ^{b}	99.99 ^{bc}	113.91 ^{a}	119.36 ^{bc}	178.07 ^{a}	180.40 ^{ab}	107.65 ^{c}	103.53 ^{ab}
T4	31.18 ^{g}	25.38 ^{g}	54.50 ^{f}	55.25 ^{g}	116.19 ^{fg}	112.53 ^{f}	46.24 ^{g}	39.25 ^{g}
T5	63.61 ^{ef}	82.03 ^{d}	92.08 ^{d}	100.05 ^{def}	135.82 ^{defg}	148.43 ^{de}	72.58 ^{f}	86.04 ^{e}
T6	67.96 ^{def}	81.52 ^{d}	94.43 ^{cd}	97.78 ^{ef}	134.78 ^{defg}	146.02 ^{e}	76.80 ^{ef}	87.97 ^{de}
T7	69.23 ^{cdef}	95.13 ^{c}	98.52 ^{bcd}	110.31 ^{cdef}	147.86 ^{bcde}	153.65 ^{cde}	89.65 ^{d}	97.56 ^{bcde}
T8	69.60 ^{cdef}	96.66 ^{bc}	98.17 ^{bcd}	114.25 ^{bcd}	143.15 ^{cdef}	163.43 ^{abcde}	91.35 ^{d}	100.0 ^{bcd}
SEM$\pm$	2.44	4.14	4.43	5.17	9.05	6.97	3.73	3.99
CD 5%	7.41	12.55	13.43	15.70	27.44	21.15	11.32	12.11
AXB								
SE(m) $\pm$AXB	6.07	4.46	5.94	5.06	10.05	9.59	4.62	4.02
SE(m) $\pm$BXA	5.13	5.25	6.22	6.27	11.74	10.02	5.03	4.82
CD 5% AXB	NS	NS	NS	NS	NS	NS	NS	NS

*Means followed by different letters differ significantly at P = 0.05.
*T1- Total removal of residue upto 1 inch and RDN (1/3 + 1/3 + 1/3),
T2- Residue incorporation/retention + RDN (1/3 + 1/3 + 1/3)
T3- Residue incorporation/retention + RDN (1/3 + 1/3 + 1/3) + Microbial Consortium (2% Spray)
T4- Residue burning + RDN (1/3 + 1/3 + 1/3)
T5- Residue incorporation/retention + RDN (43:23:33)
T6- Residue incorporation/retention + RDN (43:33:23)
T7- Residue incorporation/retention + 10 % Extra RDN (43:23:33)
T8- Residue incorporation/retention + 10 % Extra RDN (33:43:23)

so that the microbial life is less disturbed and enhances organic carbon compared to conventional tillage (Curaqueo *et al.*, 2011) which inturn improves microbial growth and multiplication. This can be very advantageous under limited P conditions (Carpenter-Boggs *et al.*, 2003), especially for crop plants which are not hosts for arbuscular mycorrhizal fungi (Wu *et al.*, 2006). The residues provide food for the growth and multiplication of microbes (Wang *et al.*, 2008). Application of microbial consortium on straw eases the decomposition of straw by microbes. These microbes also enhance the root activity and both are responsible for enhanced phosphatase activity in the maize rhizosphere (Tarafdar and Jungk, 2001). The straw enhances P adsorption in soil in same growing season (McGill and Cole, 1981).

Alkaline Phosphatase Activity

The alkaline phosphatase activity in soil at all the crop growth stages was significantly influenced



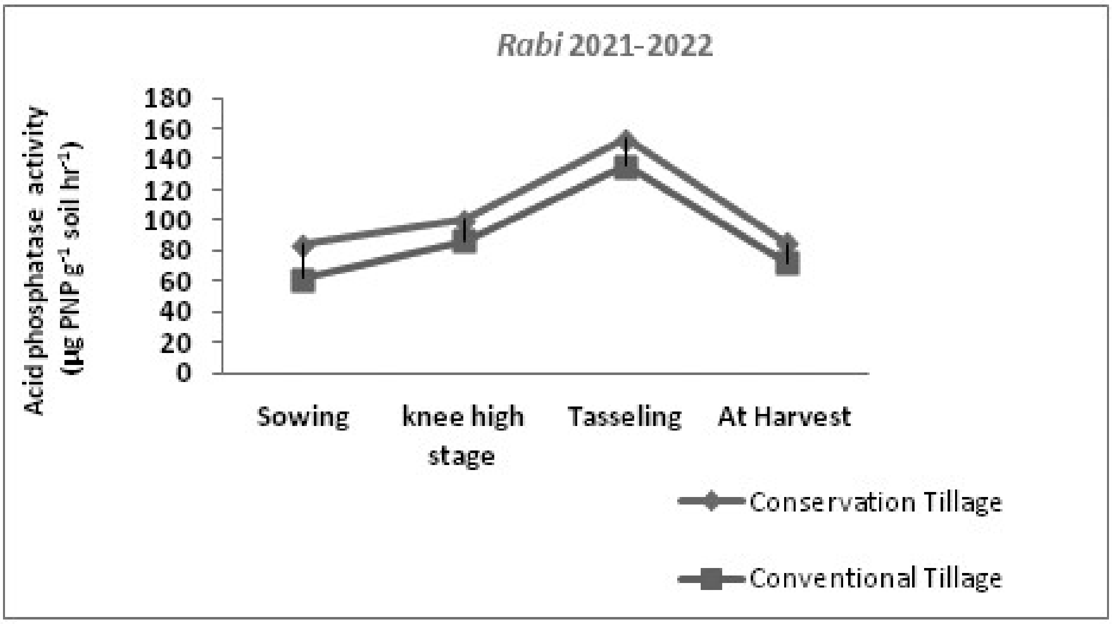


Figure 1. Impact of tillage and residue management on acid phosphatase activity (ìg PNP g^{-1} soil hr^{-1})

by tillage and residue management options. The data pertaining to effect of tillage and residue management options on alkaline phosphatase activity at all stages of crop growth was presented in Table 2 and Figure 2. The alkaline phosphatase activity increased from sowing to tasseling stage and later there was a decline upto harvest stage. Maximum alkaline phosphatase activity was recorded at tasseling stage during both the years of experiment.

During *rabi* 2020-21, conservation tillage recorded significantly higher alkaline phosphatase activity (ìg PNP g^{-1} soil hr^{-1}) at sowing (37.67), knee high stage (92.02), tasseling stage (214.46) and at harvest (97.54) compared to conventional tillage. In *rabi* 2021-22 also similar trend was noticed where the alkaline phosphatase activity (ìg PNP g^{-1} soil hr^{-1}) in conservation tillage at sowing, knee high, tasseling stages and at harvest was 38.69, 113.15, 226.35, 81.62 respectively, which was significantly superior over alkaline phosphatase activity in conventional tillage. Sepat *et al*. (2014) revealed that no tillage improved alkaline phosphatase activity by 6.1 % over conventional tillage due to minimum soil disturbance,

Table 2. Impact of tillage and residue management on alkaline phosphatase activity (ìg PNP g^{-1} soil hr^{-1}) at various crop growth stages of maize

Treatments	Sowing		Knee High Stage		Tasseling Stage		At Harvest	
Tillage								
Year	**2020-2021**	**2021-2022**	**2020-2021**	**2021-2022**	**2020-2021**	**2021-2022**	**2020-2021**	**2021-2022**
Conservation Tillage	37.67 ^{a}	38.69 ^{a}	92.02 ^{a}	113.15 ^{a}	214.46 ^{a}	226.35 ^{a}	97.54 ^{a}	81.62 ^{a}
Conventional Tillage	24.34 ^{b}	27.22 ^{b}	80.71 ^{b}	96.56 ^{b}	190.55 ^{b}	188.97 ^{b}	87.19 ^{b}	66.98 ^{b}
SEM	0.59	0.37	1.36	1.03	2.61	2.57	1.34	0.70
CD 5%	3.61	2.27	8.23	6.28	15.89	15.65	8.13	4.28
Residue management options								
T1	11.79 ^{g}	18.08 ^{f}	63.94 ^{f}	74.49 ^{e}	120.07 ^{g}	136.11 ^{f}	59.80 ^{g}	54.45 ^{f}
T2	31.05 ^{ef}	29.25 ^{e}	87.60 ^{e}	98.95 ^{d}	213.88 ^{f}	198.89 ^{e}	86.36 ^{f}	70.27 ^{e}
T3	54.52 ^{c}	46.59 ^{c}	112.21 ^{a}	128.23 ^{a}	248.70 ^{bc}	263.52 ^{bc}	125.64 ^{cd}	94.97 ^{ab}
T4	11.78 ^{g}	14.24 ^{f}	51.05 ^{g}	74.58 ^{e}	130.76 ^{g}	146.56 ^{f}	51.36 ^{g}	50.18 ^{f}
T5	26.89 ^{f}	35.22 ^{de}	92.55 ^{cde}	105.29 ^{c}	216.46 ^{ef}	202.48 ^{de}	84.55 ^{ef}	73.42 ^{de}
T6	28.80 ^{ef}	36.37 ^{de}	91.34 ^{de}	108.16 ^{c}	216.97 ^{def}	209.53 ^{de}	90.99 ^{ef}	78.89 ^{cde}
T7	39.62 ^{d}	41.30 ^{cd}	93.16 ^{bcde}	121.82 ^{b}	235.53 ^{cdef}	244.39 ^{c}	115.28 ^{d}	84.14 ^{bcd}
T8	43.62 ^{d}	42.57 ^{cd}	99.09 ^{bcde}	127.34 ^{a}	237.68 ^{bcdef}	259.84 ^{bc}	124.93 ^{cd}	88.09 ^{abc}
SEM±	2.32	2.72	4.17	1.74	9.93	10.50	3.83	3.87
CD 5%	7.03	8.26	12.64	5.28	30.13	31.84	11.62	11.73
AXB								
SE(m)± AXB	3.23	3.17	6.18	3.17	14.05	14.30	5.19	4.92
SE(m)± BXA	3.34	3.62	6.17	3.62	14.41	14.94	5.39	5.34
CD 5% AXB	NS	NS	NS	NS	NS	NS	NS	NS

* Means followed by different letters differ significantly at P = 0.05.

* T1- Total removal of residue upto 1 inch and RDN (1/3 + 1/3 + 1/3),
T2- Residue incorporation/retention + RDN (1/3 + 1/3 + 1/3)
T3- Residue incorporation/retention + RDN (1/3 + 1/3 + 1/3) + Microbial Consortium (2% Spray)
T4- Residue burning + RDN (1/3 + 1/3 + 1/3)
T5- Residue incorporation/retention + RDN (43:23:33)
T6- Residue incorporation/retention + RDN (43:33:23)
T7- Residue incorporation/retention + 10 % Extra RDN (43:23:33)
T8- Residue incorporation/retention + 10 % Extra RDN (33:43:23)

which is favourable to microbes which can release alkaline phosphatase. Omidi *et al.*, 2007 have also reported an increased alkaline phosphatase activity under no tillage, compared to conventional tillage.

Among residue management options, during *rabi* 2020-21, residue incorporation + 100 % RDN + microbial consortium (T3) recorded significantly higher alkaline phosphatase activity (ìg PNP g^{-1} soil hr^{-1}) at sowing (54.52), knee high stage (112.21), tasseling stage (248.70) and at harvest (125.64). Similar results were recorded in *rabi* 2021-22 as well *i.e.*, higher alkaline phosphatase activity (ìg PNP g^{-1} soil hr^{-1}) was recorded in T3 treatment (46.59) at sowing which was on par with residue incorporation + 10 % extra nitrogen in first split (41.30) and residue incorporation + 10 % extra nitrogen in second split (42.57). At knee high stage also T3 (128.23) treatment recorded higher alkaline phosphatase activity (ìg PNP g^{-1} soil hr^{-1}) which was

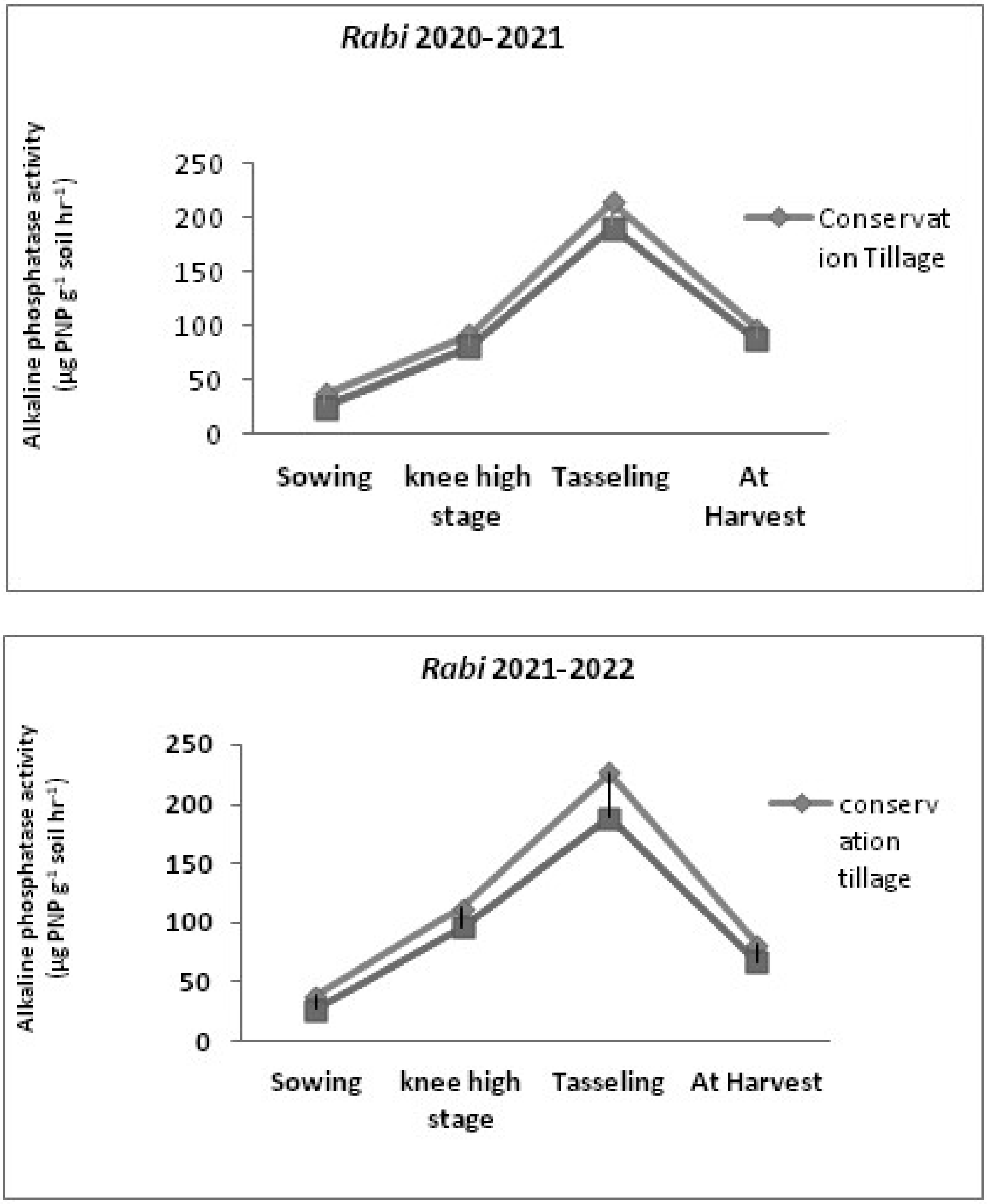


Figure 2. Impact of tillage and residue management on alkaline phosphatase activity (ìg PNP g^{-1} soil hr^{-1})

on par with T8 (127.34). At tasseling stage, T3 treatment (263.52) recorded higher alkaline phosphatase activity (ìg PNP g^{-1} soil hr^{-1}) which was on par with T7 (244.39) and T8 (259.84). At harvest, T3 (94.97), T7 (84.14) and T8 (88.09) which were on par and treatments recorded significantly higher alkaline phosphatase activity. The lowest alkaline phosphatase activity at all the crop growth stages was recorded in residue burning treatment (T4) and control (T1) in both the years, which were on par. Any direct effects due to physical destruction of the microbial population by burning would lead to decreases in microbial populations after burning in the top soil layer of the soil profile. The effects of residue burning are probably caused by volatile losses of readily available C compounds that are important energy sources for microbial activity which, in turn, could affect the accumulation of soil enzymes like alkaline phosphstase (Ravali *et al.*, 2022). There was no significant interaction observed between tillage and residue management options with respect to alkaline phosphatase activity.

Our results were consistent with the results of Nath *et al*. (2021) who observed that conventional tillage – zero tillage + application of residue increased the alkaline phosphatase activity by 4-25%. Kumar *et al*. (2019) reported that there was a decline in the activity of alkaline phosphatase due to residue burning. Yang *et al*. (2019) have reported that no tillage with 100 % residue incorporation treatment recorded significantly higher alkaline phosphatase activity compared to conventional tillage. The activities of alkaline phosphatase are mostly of microbial origin. After burning, alkaline phosphatase activity was significantly lowered. However, the alkaline phosphatase activity was found to decline gradually. This may be due to increase in available phosphorous in the soil, which inhibits extracellular synthesis of phosphatase enzyme activity (Clarholm, 1993). The residue inputs with increasing C sources potentially enhance soil microbial activity and phosphatase activities exhibit positive correlations with microbial biomass and activity in soil (Nannipieri *et al*., 2011).

Both acid phosphatase and alkaline phosphatase activities were highest at tasseling stage of crop. This is due to higher microbial population at tasseling stage. At harvest, the low activity of these enzymes might be due to lower soil moisture which is an unfavorable condition for the release of these enzymes and the rate of growth of root system is low. So there will be lower activity of these enzymes.

Available Phosphorous (kg ha^{-1})

The data pertaining to available phosphorous at all the crop growth stages was presented in Table 3. Available P status in soil at different crop growth stages was affected by tillage and residue management options. During *rabi* 2020-21, at knee high stage both tillage systems did not differ significantly with respect to available P. These findings were in accordance with the results obtained by Vogeler *et al.* (2009), who reported that available P status was not significantly affected by tillage. However, at tasseling (18.64 kg ha^{-1}) and harvest stage (18.48 kg ha^{-1}), conventional tillage recorded significantly higher available P compared to conservation tillage. In *rabi* 2021-22 also similar trend was noticed where the available P in conventional tillage at knee high stage, tasseling stage and at harvest was 15.09 kg ha^{-1}, 18.71 kg ha^{-1}, 17.85 kg ha^{-1} respectively which was significantly superior over no tillage. Ishaq *et al.* (2002) reported higher available P in deep tillage compared to minimum tillage plots. Khan *et al.* (2010) reported that deep tillage significantly improved soil available P concentration compared to minimum tillage.

Among residue management options, during *rabi* 2020-21 as well *i.e.*, higher available P was recorded in residue incorporation + 10 % treatment (17.30 kg ha^{-1}) at knee high stage, which was on par with T7 (16.93 kg ha^{-1}) and T3 (16.18 kg ha^{-1}). At tasseling stage, T8 (20.30 kg ha^{-1}) treatment recorded higher available P which was on par with T7 (19.93 kg ha^{-1}) and T3 (19.68 kg ha^{-1}). At harvest, T8 treatment (20.45 kg ha^{-1}) recorded higher available P which was on par with T7 (20.08 kg ha^{-1}). T1 treatment recorded significantly lower available P in all the crop growth stages. Similar results were recorded in 2021-22, T8 treatment recorded significantly higher available P at knee high stage (18.92 kg ha^{-1}), which was on par with T7 (18.62 kg ha^{-1}). The lowest available P was recorded in T1 (15.07 kg ha^{-1}). At tasseling stage, T8 (19.85 kg ha^{-1}) recorded higher available P which was on par with T7 (19.67 kg ha^{-1}), T3 (18.95 kg ha^{-1}) and T6 (18.48 kg ha^{-1}). At harvest, significantly higher available P was recorded in T8 (19.73 kg ha^{-1}) which was on par with T5 (18.21 kg ha^{-1}), T6 (18.25 kg ha^{-1}) and T7 (19.13 kg ha^{-1}), while the lowest available P at harvest was recorded in T1 (16.31 kg ha^{-1}). The residue incorporation/retention + 10 % extra RDN improved available P status by 23 % (2021) and 28 % (2022) compared to residue incorporation/retention + RDN treatment. The volatilization process during the burning of agricultural biomass is the reason for the decrease of soil P content Lal (2009). Similar results were obtained by Yan *et al*. (2021).

The results were also in accordance with Bhat *et al*. (1991), who reported that residue incorporated treatments showed significantly higher available P (45 kg ha^{-1}) compared to residue removal (38 kg ha^{-1}) and residue burnt treatments (32 kg ha^{-1}).

Studies have revealed that available phosphorous is strongly positively correlated with phosphatases. In this study, the soil available P is correlating with phosphatase activity at from sowing to tasseling stage (Table 3, Figure 1 and 2). This

Table 3. Impact of tillage and residue management options on available P status (kg ha^{-1}) at various crop growth stages of maize

Treatments	*Rabi* maize 2020-21			*Rabi* maize 2021-22		
	Knee High Harvest	Tasseling Stage	At Stage	Knee High Stage	Tasseling Stage	At Harvest
Tillage						
Conservation Tillage	13.78 ^{b}	17.25 ^{b}	16.28 ^{b}	16.67 ^{a}	17.41 ^{b}	16.98 ^{b}
Conventional Tillage	15.09 ^{a}	18.71 ^{a}	17.85 ^{a}	17.65 ^{a}	18.64 ^{a}	18.48 ^{a}
SEM	0.21	0.23	0.22	0.35	0.19	0.20
CD 5%	1.26	1.38	1.34	NS	1.15	1.44
Residue management options						
T1	11.43 ^{f}	15.55 ^{f}	12.45 ^{f}	15.07 ^{g}	15.83 ^{g}	16.31 ^{g}
T2	13.21 ^{e}	17.71 ^{e}	14.59 ^{e}	16.66 ^{ef}	17.09 ^{efg}	16.43 ^{fg}
T3	16.18 ^{c}	19.68 ^{d}	19.00 ^{bcd}	17.69 ^{bcd}	18.95 ^{bcdef}	17.31 ^{efg}
T4	11.50 ^{f}	15.25 ^{f}	14.75 ^{e}	16.10 ^{f}	16.33 ^{fg}	16.50 ^{efg}
T5	14.33 ^{de}	17.58 ^{e}	17.48 ^{d}	17.10 ^{de}	17.98 ^{def}	18.21 ^{d}
T6	14.58 ^{d}	17.83 ^{e}	17.73 ^{cd}	17.10 ^{cde}	18.48 ^{cdef}	18.25 ^{cd}
T7	16.93 ^{bc}	19.93 ^{cd}	20.08 ^{ab}	18.62 ^{ab}	19.67 ^{abcde}	19.13 ^{bcd}
T8	17.30 ^{bc}	20.30 ^{cd}	20.45 ^{a}	18.92 ^{a}	19.85 ^{abc}	19.73 ^{bcd}
SEM$\pm$	0.44	0.43	0.43	0.52	0.88	0.56
CD 5%	1.32	1.30	1.29	1.00	2.67	1.69
AXB						
SE(m)$\pm$ AXB	0.61	0.62	0.58	1.15	1.10	0.66
SE(m)$\pm$ BXA	0.61	0.61	0.59	0.98	1.20	0.73
CD 5% AXB	NS	NS	NS	NS	NS	NS

* Means followed by different letters differ significantly at P = 0.05.
* T1- Total removal of residue upto 1 inch and RDN (1/3 + 1/3 + 1/3),
T2- Residue incorporation/retention + RDN (1/3 + 1/3 + 1/3)
T3- Residue incorporation/retention + RDN (1/3 + 1/3 + 1/3) + Microbial Consortium (2% Spray)
T4- Residue burning + RDN (1/3 + 1/3 + 1/3)
T5- Residue incorporation/retention + RDN (43:23:33)
T6- Residue incorporation/retention + RDN (43:33:23)
T7- Residue incorporation/retention + 10 % Extra RDN (43:23:33)
T8- Residue incorporation/retention + 10 % Extra RDN (33:43:23)

indicated that as the phosphatases concentration increases, the P availability to the crop is also being increased. The increase in the available P status in the residue incorporated treatments were attributed to the increased substrates of soil phosphatases resulting from the rice straw retention and incorporation and the increased microbial activity due to phosphatases in soil are derived primarily from microorganisms (Turner and Haygarth 2005). Conventional tillage with residue retention created substrate for the growth and multiplication of microbes especially the fungi (*Aspergillus* and *Pencillium*) and bacteria (*Serratia* sp.), which are the major microorganisms responsible for phosphatase activity in soil and enhanced P availability, compared to straw removal and straw burnt treatments. The increase in available P content in soil from knee high stage to tasseling stage might be because as the decomposition process precedes, there will be more P release from the residue. The 10 % increased application of nitrogen in second split (T8) and in first split (T7) treatments, helped in modifying C:N ratio of the residue and relatively eased the decomposition process compared to other treatments and helped in release of more P compared to rest of the treatments.

CONCLUSION

Conservation tillage improved both acid and alkaline phosphatase activities at all crop growth stages of maize during both the years and it was more pronounced during second year of experiment. Among residue management treatments, treatment with residue incorporation/retention + RDF + Microbial consortium (T3) and residue incorporation/retention + 10 % extra RDN (T7 and T8) enhanced phosphatase activities during entire crop growth period. The conventional tillage and residue incorporation/retention + 10 % extra RDN (T8) improved available P status in soil during the crop growth period. Thus, conventional tillage and residue incorporation helps in improving P fertility of soil and helps in sustaining the soil productivity. Results revealed that there is a strong positive relation between phosphorous availability and phosphatases activity in soil. The residue burning and residue removal lowered the activities of acid and alkaline phosphatases and in turn lowered the available P status. The residue incorporation/retention + 10 % extra RDN improved available P status by 23 % (2021) – 28 % (2022) compared to residue incorporation/retention + RDN treatment.

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Research Article
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PRODUCTIVITY AND PROFITABILITY OF HDPS COTTON INFLUENCED BY GENOTYPES AND INM PRACTICES

G. VINAY[1], K. P. VANI[2], B. PADMAJA[3], G. JAYASREE[4], S. TRIVENI[5] and M. YAKADRI[1]

[1]Department of Agronomy, College of Agriculture, Rajendranagar

[2]Department of Agronomy, Agricultural College, Sircilla

[3]AICRP on Weed Management, Rajendranagar

[4] Department of Soil Science and Agricultural Chemistry, Agricultural College, Rajendranagar

[5]Department of Microbiology and Bio energy, College of Agriculture, Rajendranagar

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ABSTRACT

A field experiment was conducted at College Farm, Agricultural College, Rajendranagar, Hyderabad, during *kharif,* 2019-20 and 2020-21 to study effect of genotypes and integrated nutrient management practices on profitability of HDPS cotton. Experiment was laid out in Split plot design, with two genotypes as main plots (M) and nine Integrated Nutrient Management practices as sub plots (S). Among genotypes, higher lint yield (919; 836 kg ha^{-1}), seed yield (1604; 1468 kg ha^{-1}), stalk yield (6412; 6110 kg ha^{-1}), net returns (93929; 88387 ¹ ha^{-1}) and B: C ratio (2.74; 2.72) were obtained by *Bt* variety (KCH-14 K59 BG II) compared Non-*Bt* variety (ADB-542) during *kharif,* 2019-20 and 2020-21, respectively. While, among integrated nutrient management practices, significantly higher lint yield (1157; 1047 kg ha^{-1}), seed yield (1983; 1807 kg ha^{-1}) and stalk yield (7190; 6853 kg ha^{-1}) and net returns (123795; 115397) were observed with 100% RDF + soil application *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest (S_5) during both years and was comparable with 100 % RDF + Foliar spray of *Jeevamrutha* @ 5% at 15 days interval up to harvest (S_7) and 100 % RDF (S_3), respectively. However, higher B: C ratio (3.46; 3.49) was obtained with 100% RDF (S_3) during both seasons.

Key words: HDPS cotton, *Jeevamrutha*, INM, Lint yield, Net returns and B: C ratio.

Cotton (*Gossypium hirsutum* L.) is one of the major commercial crops of India, popularly known as 'White gold' and 'King of fibres' for its role in the national economy in the form of foreign exchange earnings and employment generation. Cotton provides fibre, feed, fuel and vegetable oil (Kumar *et al.*, 2017). It is the world's leading source of natural textile fibre and fifth largest oilseeds crop which covers 40% of the global textile need and 3.3 % of edible oil respectively (Nagender *et al.,* 2017a).

It is grown mainly in tropical and subtropical regions of more than 80 countries in the world. This crop provides livelihood to 60 million people in India by way of support to agriculture, processing and textiles and it contributes about 29 % of the national GDP (Khadi *et al*., 2010). In India it is grown in an area of 13.28 m ha with production of 35.24 m bales, and productivity of 491 kg ha^{-1}. Among different states, higher area (4.54 m ha) and production (10.1 m bales) was recorded in Maharashtra while, productivity was recorded from Punjab (690 kg ha^{-1}). In Telangana cotton grown in area of 2.35 m ha with the production of 5.7 m bales and productivity of 418 kg ha^{-1} (CCI, 2021).

Bt cotton in India was introduced in the year 2002 which brought a significant improvement in the cotton production taking its production levels from 13 million bales in 2002-03 to 40 million bales by 2010-11 (Narala and Reddy, 2010). However, this trend did not last long, in the recent past production levels of cotton are seen stagnant across the country at around 35 million bales due to various agronomic constraints. On the other hand cost of cotton production is escalating due to increased labour demand, increased labour costs, increased seed costs, and increased costs for cotton picking and nutrient requirements. Country's population is growing at 1.9 % and demands for food and fibre continue to grow and putting pressure on the limited arable land available (Nagender *et al.,* 2017b). All these facts point to the dire need for sustainable practices. So, to sustain the productivity, high density planting systems, with narrow and ultra-narrow spacing developing suitable management options for improving yields and also to improve input use efficiency is the need of hour.

A high density planting system (HDPS) leading to more rapid canopy closure and decreased

Email: vinaygadipe6859@gmail.com

soil water evaporation, is becoming popular to address water scarcity challenges. In many countries, narrow row plantings have been adopted after showing improvement in cotton productivity (Ali *et al.*, 2010). The adoption of HDP, along with good fertilizer management and improved genotypes, may become a viable approach in escalating the production levels from current stagnant levels primarily under rainfed hirsutum (upland) cotton growing areas.

Intensive cropping and indiscriminate fertilizer application depleted available NPK in almost all soils in India. Hence replenishment of shovelled out nutrients is very essential, especially when exhaustive crops like cotton is cultivated. The commercial cultivation of Bt. Hybrids is more profitable and relatively safe for the environment due to 50-75 % reduction in pesticide application. But Bt cotton is known to draw huge quantities of nutrients especially nitrogen than the hybrids and varieties, which will have serious repercussions on already depleted soil fertility status. Trends of high nitrogen requirement by fast expanding Bt. hybrids in India on one hand and rapid depletion of nutrients in the soils warrants improvement in cotton yield through agronomic management by integrated nutrient management to restore the soil fertility and sustain crop productivity and fully harness its economic benefits (Vani *et al.,* 2020). Integrated use of chemical fertilizers and organic manures is not only essential for achieving higher yields but also plays crucial role in improving soil health. Hence for maintaining soil physicochemical and biological properties and increasing soil productivity, use of FYM, vermicompost, *Jeevamrutha* alone or combination may prove to be beneficial (Patil *et al.,* 2016).

Keeping the above facts in view, the present study entitled "Productivity and profitability of HDPS cotton influenced by genotypes and INM practices" was carried out at College farm, College of Agriculture, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad during *kharif*, 2019-20 and 2020-21.

MATERIAL AND METHODS

The field experiment was conducted at College Farm, Agriculture College, Rajendranagar, Southern Telangana Zone which is geographically situated at 17°32'N Latitude, 78°41' E Longitude and altitude of 542.6 m above mean sea level. Soil of the experimental site is sandy clay loam, slightly alkaline and non-saline, low in organic carbon (0.51%), available N (138 kg ha^{-1}), high in phosphorus (65 kg ha^{-1}) and medium in potassium (286 kg ha^{-1}). Field trial was conducted in *kharif,* 2019-20 and 2020-21 in split plot design with two genotypes viz., **M_1**-*Bt* (KCH-14K59 BG II), **M_2**-Non- *Bt* (ADB-542) as main plots and nine integrated nutrient management practices *viz.,* **: S_1**-No fertilizer, **S_2**-75 % RDF, **S_3**-100 % RDF, **S_4**-75 % RDF + Soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest, **S_5**-100 % RDF + Soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest, **S_6**-75 % RDF + Foliar spray of *Jeevamrutha* @ 5% at 15 days interval up to harvest, **S_7**-100 % RDF + Foliar spray of *Jeevamrutha*@ 5% at 15 days interval up to harvest, **S_8**-Soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest (Alone), **S_9**-Soil application of *Jeevamrutha* @ 500 L ha^{-1} + Foliar spray of *Jeevamrutha* @ 5% at 15 days interval up to harvest, as subplots replicated thrice. Fertilizers were applied as per framed treatments following standard protocols of Bt and Non Bt cotton. For Bt cotton, RDF @120: 60: 60 kg NPK $ha^{-1}$was adopted, While N and K were applied in four equal splits (*i.e.,* at 20, 40, 60 and 80 DAS) whereas entire dose of Phosphorus was applied as basal. Nitrogen and potassium were applied in three equal splits (i.e., at 30, 60, and 90 DAS) to Non Bt cotton (RDF: 90: 45: 45 NPK ha-1) and Phosphorus was applied as basal. Urea, DAP and MOP are sources of N, P_2O_5 and K_2O respectively. *Jeevamrutha* was made according to Yogananda Babu's method (2015) by mixing 200 litres of water with 10 kg fresh cow dung and 10 liters of cow urine (desi), 2 kg jaggery, 2 kg flour of chickpea, and 100 g antennae soil in a barrel. The fermented mixture was kept in the shade and was stirred thoroughly twice a day (morning and evening) in clockwise direction with help of wooden stick for three days. It will produce a mild foul odour after three days which indicates its readiness to use. *Jeevamrutha* @ 500 L ha^{-1} was applied uniformly to the soil in four treatments ($S_{4,}$ S_5, S_8, and S_9) from 15 DAS to harvest with 15 days interval. *Jeevamrutha* @ 5% foliar spray was applied with Knapsack sprayer in three treatments ($S_{6,}$ S_7, and S_9) from 15 DAS to crop harvest with a 15 days interval. Gross plot and net plot size were 6.0 x 4.2 m and 3.6 x 3.0 m, with a spacing of 60 x 30 cm during both seasons.

Seed cotton and stalk yields were estimated from net plot. Seed and lint yield were measured after ginning. The expenditure incurred from sowing to harvest was worked out for each treatment and expressed in ₹ ha^{-1} as cost of cultivation. Gross returns (₹ ha^{-1}) were calculated by multiplying seed cotton yield with the prevailing market price (Perin *et al*., 1979). Net returns (₹ ha^{-1}) were obtained by subtracting cost of cultivation from gross returns for each treatment. Benefit cost ratio was calculated by dividing gross returns with cost of cultivation for each treatment. A detail of cost of cultivation is presented in Table 3, 4 and 5. Data was analysed statistically applying analysis of variance technique for split plot design. The significance was tested by 'F' test (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Lint yield (kg ha^{-1}) was significantly influenced by different genotypes and integrated nutrient management practices however, their interaction effect was nonsignificant for HDPS cotton and followed a similar trend during both the years of experimentation (Table 1)

Among genotypes, M_1 (919 and 836 kg ha^{-1}) had statistically superior level of lint yield than M_2 (546 and 490 kg ha^{-1}) during both years. Better performance of Bt cotton was ascribed to higher boll number, heavier boll weight and higher ginning percentage leading to more lint yield than non Bt, due to low photosynthetic ability might decreased lint yield. Similar results were confirmed by Kaur *et al.* (2019) Singh *et al.* (2018) and Deshpande *et al*. (2015).

Among nutrient management practices, over two successive years, S_5 *i.e.,*100 % RDF + Soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest recorded higher lint yield of 1157 and 1047 kg ha^{-1} and was on par with S_7 [100 % RDF + Foliar spray of *Jeevamrutha* @ 5% at 15 days interval up to harvest] (1096 and 989 kg ha^{-1}) and S_3 [100 % RDF] (1040 and 931 kg ha^{-1}) respectively. The no fertilizer treatment (S_1) produced lowest lint yield (298 and 256 kg ha^{-1}) in 2019-20 and 2020-21, respectively. Complementary alliance of inorganic and liquid organic manure (*Jeevamrutha*) improved the ready release of nutrients from inorganic fertilisers as well as from organic manures may resulted in fertility improvement and higher lint yield production. No fertilizer treatment leads to nutrient imbalance which affects the lint yield in cotton. These results were in line with those of Ali and Ahmad (2021), Kumar *et al.* (2019)

Seed Yield (kg ha^{-1})

Genotypes had a significant effect on seed yield of cotton. Higher seed yield of 1604 and 1468 kg ha^{-1} was recorded by $\mathbf{M_1}$ i.e., *Bt* KCH - 14K59 BG II followed by $\mathbf{M_2}$ [non *Bt* ADB 542] (1085 and 978 kg ha^{-1}) during 2019-20 and 2020-21, respectively. Better yield attributing characters *i.e.*, Number sympodial branches, No of bolls, boll weight and seed index of Bt cotton resulted in higher seed yield compared to non Bt cotton. These results were in conformity with Kaur *et al.* (2019) and Singh *et al*. (2018).

Data revealed that in comparison to no fertilizer, all other nutrient management practices increased seed yield of cotton. Higher seed yield was noticed with S_5 *i.e.,* 100 % RDF + Soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest (1983 and 1807 kg ha^{-1}) which was at equivalence with S_7 [100 % RDF + Foliar spray of Jeevamrutha @ 5% at 15 days interval up to harvest] (1905 and 1730 kg ha^{-1}), while, lower seed yield was obtained by S_1 [No fertilizer] (620 and 539 kg ha^{-1}). Increase in seed yield with the liquid organic manure (*Jeevamrutha*) and inorganics is due to transformed nutrient availability resulting in improved yield attributing characters *viz.* bolls/plant and boll weight (g) and seed index of cotton and thus seed yield. Similar findings were reported by Kumar *et al*. (2019).

Stalk yield (kg ha^{-1})

During two years of investigation, *Bt* KCH-14K59 BG II, produced more stalk yield (6412 and 6110 kg ha^{-1}) and differed significantly with non-*Bt*, ADB - 542 (5756 and 5530 kg ha^{-1}). *Bt* cotton higher stalk yield might be due to improvement in assimilation of photosynthates at various stages of crop growth. Non Bt cotton has obtained less growth and yield attributes which resulted in less biomass production thus low stalk yield. These results are in accordance with results indicated by Nagendar *et al*. (2017b), and Gangaiah *et al*. (2013).

Significantly higher stalk yield was observed with S_5 *i.e.* 100 % RDF + Soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest (7190 and 6853 kg ha^{-1}) similar with S_7 *i.e.* 100 % RDF + Foliar spray of *Jeevamrutha* @ 5%

Table 1. Seed, Lint and Stalk yield (kg ha^{-1}) of HDPS cotton as influenced by Genotypes and Integrated Nutrient Management

Treatments	Lint yield		Seed yield		Stalk yield	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
	Main plot					
M_1	919	836	1604	1468	6412	6110
M_2	546	490	1085	978	5756	5530
SE(m)±	26.1	22.8	42.9	35.1	90.1	73.9
CD (p=0.05)	159	139	261	214	548	450
Sub plot						
S_1	298	256	620	539	4478	4379
S_2	664	615	1268	1183	6051	5699
S_3	1040	931	1822	1645	6800	6545
S_4	783	711	1454	1325	6329	6100
S_5	1157	1047	1983	1807	7190	6853
S_6	722	661	1358	1250	6276	5916
S_7	1096	989	1905	1730	6952	6727
S_8	388	346	789	710	5165	4907
S_9	445	407	898	821	5513	5255
SE(m)±	51.8	47.4	71.5	60.8	161.9	142.5
CD (p=0.05)	149	136	206	175	466	411
Interaction						
M×S						
SE(m)±	73.8	67.2	104.6	88.3	233.9	203.9
CD (p=0.05)	NS	NS	NS	NS	NS	NS
S×M						
SE(m)±	73.2	67.1	101.2	85.9	228.9	201.6
CD (p=0.05)	NS	NS	NS	NS	NS	NS

Main plots – **Genotypes**
M_1- *Bt* (KCH – 14K59 BG II)
M_2- Non- *Bt* (ADB – 542)

Sub plots-**Integrated Nutrient Management:**
S_1- No fertilizer
S_2- 75 % RDF
S_3- 100 % RDF
S_4- 75 % RDF + Soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest
S_5- 100 % RDF + Soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest
S_6- 75 % RDF + Foliar spray of *Jeevamrutha* @ 5% at 15 days interval up to harvest
S_7- 100 % RDF + Foliar spray of *Jeevamrutha*@ 5% at 15 days interval up to harvest
S_8- Soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest (Alone)
S_9- Soil application of *Jeevamrutha* @ 500 L ha^{-1} + Foliar spray of *Jeevamrutha* @ 5% at 15 days interval up to harvest.

at 15 days interval up to harvest (6952 and 6727 kg ha^{-1}) whereas, S_1 *i.e.* No fertilizer (4478 and 4379 kg ha^{-1}) produced lowest stalk yield among integrated nutrient management practices during 1st and 2nd year of study respectively. The increase in stalk yield with liquid organic manure (*Jeevamrutha*) and inorganic fertilizers treatment might be due to higher photosynthetic activity, better supply of carbohydrates leading to more number of branches and dry matter accumulation. Low stalk yield obtained in no fertilizer treatment because of less growth as well as yield attributes. The findings corroborate the results of Singh *et al.* (2020), Megha *et al.* (2017) and Amith *et al.* (2017).

The interaction effect of genotypes and integrated nutrient management practices on Lint, seed and stalk yield of cotton was not significant.

Economics

Economics is ultimate scale on which success or failure of treatment in getting recommendation is finalized. Data recorded under different components of economics revealed that gross return increased with increasing seed cotton yield, stalk yield obtained under different treatments. Economics was significantly influenced by genotypes and INM as presented in Table 2, 3, 4 & 5 and graphically illustrated in Figure 1 & 1a.

Cost of cultivation (₹ ha^{-1})

The total cost of cultivation is varied due to genotypes and integrated nutrient management. This was mainly due to differences in seed, fertilizers, *Jeevamrutha* and cotton picking across the treatments.

With *Bt* KCH-14K59 BG II, highest cost of cultivation (53016 and 50431 ₹ ha^{-1}) was noticed in 2019-20 and 2020-21, respectively. Comparatively lowest cost of cultivation was observed with non *Bt* ADB -542, (47032 and 44867 ₹ ha^{-1}).

Out of nine integrated nutrient management practices, S_5 *i.e.*, 100 % RDF + soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest had resulted in maximum cost of cultivation with 59065 and 56555 ₹ ha^{-1} followed by S_4 *i.e.*75 % RDF + soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest, (57920 and 55410 ₹ ha^{-1}), while cost of cultivation was lower with S_1 *i.e.,* No fertilizer (37310 and 34800 ₹ ha^{-1}) in *kharif*, 2019-20 and 2020-21, respectively. In S_5 and S_4 treatments, recommended dose of fertilizers and soil application of *Jeevamrutha* at 15 days interval up to harvest was done during cropping season, due to higher fertilizers cost and purchase of *Jeevamrutha* ingredients, preparation and application had incurred higher cost of cultivation compared to RDF alone and *Jeevamrutha* Foliar spraying. Lower cost of cultivation was recorded in no fertilizer treatment in both years which might be due to no fertilizer use. Similar findings were reported by Siddu and Aladakatti (2021) Kumari *et al*. (2018), Channagoudar *et al.* (2015) and Rudragouda *et al.* (2014).

Gross returns (₹ ha^{-1})

Total gross returns differed between treatments due to seed cotton yield variations caused by genotype and integrated nutrient management practices.

Among the genotypes, *Bt,* KCH - 14K59 BG II registered significantly higher gross returns (146945 and 138817 ₹ ha^{-1}) during two years of experimentation over non-*Bt,* ADB-542, (94990 and 88436 ₹ ha^{-1}). Highest gross returns of *Bt* genotype was due to higher seed cotton yield than non *Bt,* ADB-542 genotype. Similar findings were reported by Nagender *et al.* (2017a) and Joshi *et al.* (2011).

It is obvious from the data that various integrated nutrient management practices, S_5 *i.e.* 100 % RDF + Soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest accrued maximum gross returns of 182860 and 171952 ₹ ha^{-1} at equivalence with S_7 *i.e.* 100 % RDF + Foliar spray of *Jeevamrutha* @ 5% at 15 days interval up to harvest, (174837 and 163773 ₹ ha^{-1}) and S_3 [100% RDF] (166725 and 155211 ₹ ha^{-1}), while lowest gross returns (53492 and 47917 ₹ ha^{-1}) were observed with S_1 [No fertilizer]. Integration of recommended dose of fertilizer + soil and foliar application of *Jeevamrutha* resulted in increased utilization of nutrients, moisture, light and space which helped in increased seed cotton and stalk yield, ultimately lead to higher gross returns in S_5 and S_7 treatments. These findings are also consistent with those of Siddu and Aladakatti (2021), Gacche *et al*. (2018) and Channagoudar *et al.* (2015)

Table 2. Economics of HDPS cotton as influenced by Genotypes and Integrated Nutrient Management

Treatments	Cost of cultivation (₹ ha^{-1})		Gross returns (₹ ha^{-1})		Net returns (₹ ha^{-1})		B:C ratio	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Main plot								
M_1	53016	50431	146945	138817	93929	88387	2.74	2.72
M_2	47032	44867	94990	88436	47688	43568	1.99	1.95
SE(m)±			4260	3674	3299	3110	0.04	0.07
CD (p=0.05)			25919	22349	20073	18918	0.26	0.40
Sub plot								
S_1	37310	34800	53492	47917	16182	13117	1.42	1.36
S_2	45745	43235	112521	108379	66777	65145	2.43	2.47
S_3	46890	44380	166725	155211	119836	110832	3.52	3.46
S_4	57920	55410	130330	122678	72411	67268	2.23	2.20
S_5	59065	56555	182860	171952	123795	115397	3.07	3.01
S_6	50045	47535	121162	115128	71117	67594	2.39	2.39
S_7	51190	48680	174837	163773	123648	115094	3.38	3.33
S_8	49485	46975	68551	63599	19067	16624	1.37	1.34
S_9	53785	51275	78229	74001	24444	22726	1.45	1.43
SE(m)±			6623	6056	6135	5774	0.08	0.09
CD (p=0.05)			19075	17442	17672	16631	0.23	0.25
Interaction								
M×S								
SE(m)±			9804	8871	8821	8303	0.11	0.13
CD (p=0.05)			NS	NS	NS	NS	NS	NS
S×M								
SE(m)±			9366	8564	8677	8166	0.11	0.13
CD (p=0.05)			NS	NS	NS	NS	NS	NS

Main plots **– Genotypes**
M_1- *Bt* (KCH – 14K59 BG II)
M_2- Non- *Bt* (ADB – 542)
Sub plots-**Integrated Nutrient Management:**
S_1- No fertilizer
S_2- 75 % RDF
S_3- 100 % RDF
S_4- 75 % RDF + Soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest
S_5- 100 % RDF + Soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest
S_6- 75 % RDF + Foliar spray of *Jeevamrutha* @ 5% at 15 days interval up to harvest
S_7- 100 % RDF + Foliar spray of *Jeevamrutha*@ 5% at 15 days interval up to harvest
S_8- Soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest (Alone)
S_9- Soil application of *Jeevamrutha* @ 500 L ha^{-1} + Foliar spray of *Jeevamrutha* @ 5% at 15 days interval up to harvest.

Table 3. Cost of cultivation (ha^{-1}) of HDPS cotton (2019-20) as influenced by Genotypes and Integrated Nutrient management

Treat ments		Land preparation	Fertilizers	Seed cost	Sowing	Hand weeding and Herbicide application	Jeevamrutha Ingredients	Jeevamrutha soil application	Jeevamrutha Foliar spraying	Plant protection and spraying	Picking and Harvesting	Total production cost
M_1	S_1	6750	0	3450	3600	7310	0	0	0	10375	7800	39,825
	S_2	6750	3925	3450	3600	7310	0	0	0	10375	12000	48,960
	S_3	6750	5234	3450	3600	7310	0	0	0	10375	12000	50,269
	S_4	6750	3925	3450	3600	7310	8875	3300	0	10375	12000	61,135
	S_5	6750	5234	3450	3600	7310	8875	3300	0	10375	12000	62,444
	S_6	6750	3925	3450	3600	7310	450	0	3850	10375	12000	53,260
	S_7	6750	5234	3450	3600	7310	450	0	3850	10375	12000	54,569
	S_8	6750	0	3450	3600	7310	8875	3300	0	10375	7800	51,460
	S_9	6750	0	3450	3600	7310	9325	3300	3850	10375	7800	55,760
M_2	S_1	6750	0	700	3600	7310	0	0	0	10375	6300	35,335
	S_2	6750	2944	700	3600	7310	0	0	0	10375	9300	42,529
	S_3	6750	3925	700	3600	7310	0	0	0	10375	9300	43,510
	S_4	6750	2944	700	3600	7310	8875	3300	0	10375	9300	54,704
	S_5	6750	3925	700	3600	7310	8875	3300	0	10375	9300	55,685
	S_6	6750	2944	700	3600	7310	450	0	3850	10375	9300	46,829
	S_7	6750	3925	700	3600	7310	450	0	3850	10375	9300	47,810
	S_8	6750	0	700	3600	7310	8875	3300	0	10375	6300	47,510
	S_9	6750	0	700	3600	7310	9325	3300	3850	10375	6300	51,810

Table 4. Cost of cultivation (ha^{-1}) of HDPS cotton (2020-21) as influenced by Genotypes and Integrated Nutrient management

Treatments		Land preparation	Fertilizers	Seed cost	Sowing	Hand weeding and Herbicide application	Jeevamrutha Ingredients	Jeevamrutha soil application	Jeevamrutha Foliar spraying	Plant protection and spraying	Picking and Harvesting	Total production cost
M_1	S_1	6750	0	3600	3600	7400	0	0	0	9550	7200	36,700
	S_2	6750	3925	3600	3600	7400	0	0	0	9550	11400	46,375
	S_3	6750	5234	3600	3600	7400	0	0	0	9550	11400	47,684
	S_4	6750	3925	3600	3600	7400	8875	3300	0	9550	11400	58,550
	S_5	6750	5234	3600	3600	7400	8875	3300	0	9550	11400	59,859
	S_6	6750	3925	3600	3600	7400	450	0	3850	9550	11400	50,675
	S_7	6750	5234	3600	3600	7400	450	0	3850	9550	11400	51,984
	S_8	6750	0	3600	3600	7400	8875	3300	0	9550	7200	48,875
	S_9	6750	0	3600	3600	7400	9325	3300	3850	9550	7200	53,175
M_2	S_1	6750	0	700	3600	7400	0	0	0	9550	6000	32,900
	S_2	6750	2944	700	3600	7400	0	0	0	9550	9000	40,094
	S_3	6750	3925	700	3600	7400	0	0	0	9550	9000	41,075
	S_4	6750	2944	700	3600	7400	8875	3300	0	9550	9000	52,269
	S_5	6750	3925	700	3600	7400	8875	3300	0	9550	9000	53,250
	S_6	6750	2944	700	3600	7400	450	0	3850	9550	9000	44,394
	S_7	6750	3925	700	3600	7400	450	0	3850	9550	9000	45,375
	S_8	6750	0	700	3600	7400	8875	3300	0	9550	6000	45,075
	S_9	6750	0	700	3600	7400	9325	3300	3850	9550	6000	49,375

Table 5. Cost of resources used in the present study

SOURCE	PRICE/AMOUNT (₹)	
	2019-20	2020-21
Labour	Adult man-₹ 350.00 day^{-1}	Adult man-₹ 350.00 day^{-1}
	Women-₹ 300.00 day^{-1}	Women-₹ 300.00 day^{-1}
Seed (Non Bt Cotton: ADB-542)	₹ 70 kg^{-1}	₹ 70 kg^{-1}
Seed (Bt Cotton: Jadoo)	690/- 450 g	720/- 450 g
Cultivator	₹ 1500 hr^{-1}	₹ 1500 hr^{-1}
Rotovator	₹ 1500 hr^{-1}	₹ 1500 hr^{-1}
Urea	₹ 5.9 kg^{-1}	₹ 5.9 kg^{-1}
Di ammonium phosphate	₹ 21.6 kg^{-1}	₹ 21.6 kg^{-1}
Murate of Potash	₹ 11.6 kg^{-1}	₹ 11.6 kg^{-1}
Jaggery	₹ 70 kg^{-1}	₹ 70 kg^{-1}
Pulse flour	₹ 80 kg^{-1}	₹ 80 kg^{-1}
Cow urine	₹ 5 $litre^{-1}$	₹ 5 $litre^{-1}$
Cow dung	₹ 0.5 kg^{-1}	₹ 0.5 kg^{-1}
Pendimethalin	₹ 450 $litre^{-1}$	₹ 450 $litre^{-1}$
Quizalofop ethyl + pyrithiobac sodium	₹ 950 0.25 $litre^{-1}$	₹ 950 0.25 $litre^{-1}$
Imidachlorprid	₹ 1200 $litre^{-1}$	₹ 1200 $litre^{-1}$
Flonicamid	₹ 2700 kg^{-1}	₹ 2700 kg^{-1}
Monocrotophos	₹ 450 $litre^{-1}$	₹ 450 $litre^{-1}$
Profenophos	₹ 800 $litre^{-1}$	₹ 800 $litre^{-1}$
Neem seed kernal extract1500ppm	₹ 650 $litre^{-1}$	₹ 650 $litre^{-1}$
Emamectin benzoate	₹ 2200 kg^{-1}	-
Seed cotton	₹ 5825quintal $^{-1}$	₹ 6025 quintal $^{-1}$

Net returns (₹ ha^{-1})

The total net returns differed between treatments due to differences in cultivation costs and gross returns attributed by genotypes and integrated nutrient management practices. Significantly higher net returns (93929 and 88387 ha^{-1}) was obtained by *Bt* KCH-14K59 BG II in 2019-20 and 2020-21, respectively. While, lowest net returns (47688 and 43568 ha^{-1}) was noticed with non *Bt* ADB-542. Though cost of cultivation (Table 2, 3, 4 and 5) was higher in *Bt* KCH-14K59 BG II, higher gross returns as a result of increased economic produce resulted in higher net returns over non *Bt* ADB-542. The results are in conformity with the findings of Gangaiah *et al.* (2013) and Sankaranarayanan *et al.* (2011).

Out of nine integrated nutrient management practices, S_5 *i.e.* 100 % RDF + soil application of *Jeevamrutha* @ 500 L ha^{-1} at 15 days interval up to harvest obtained significantly higher net returns (123795 and 115397 ₹ ha^{-1}) which was in parity with S_7 [100 % RDF + Foliar spray of *Jeevamrutha* @ 5% at 15 days interval up to harvest] (123648 and 115094 ₹ ha^{-1}) and S_3 [100% RDF] (119836 and 110832 ₹ ha^{-1}), while lowest net returns (16182and 13117 ₹ ha^{-1}) was found with S_1 [No fertilizer] in two years. Higher net returns in all integrated nutrient management treatments as compared to no fertilizer treatment was due to higher seed cotton and stalk yield. Also all treatments associated with soil and foliar application was better than no fertilizer with regard to net monetary

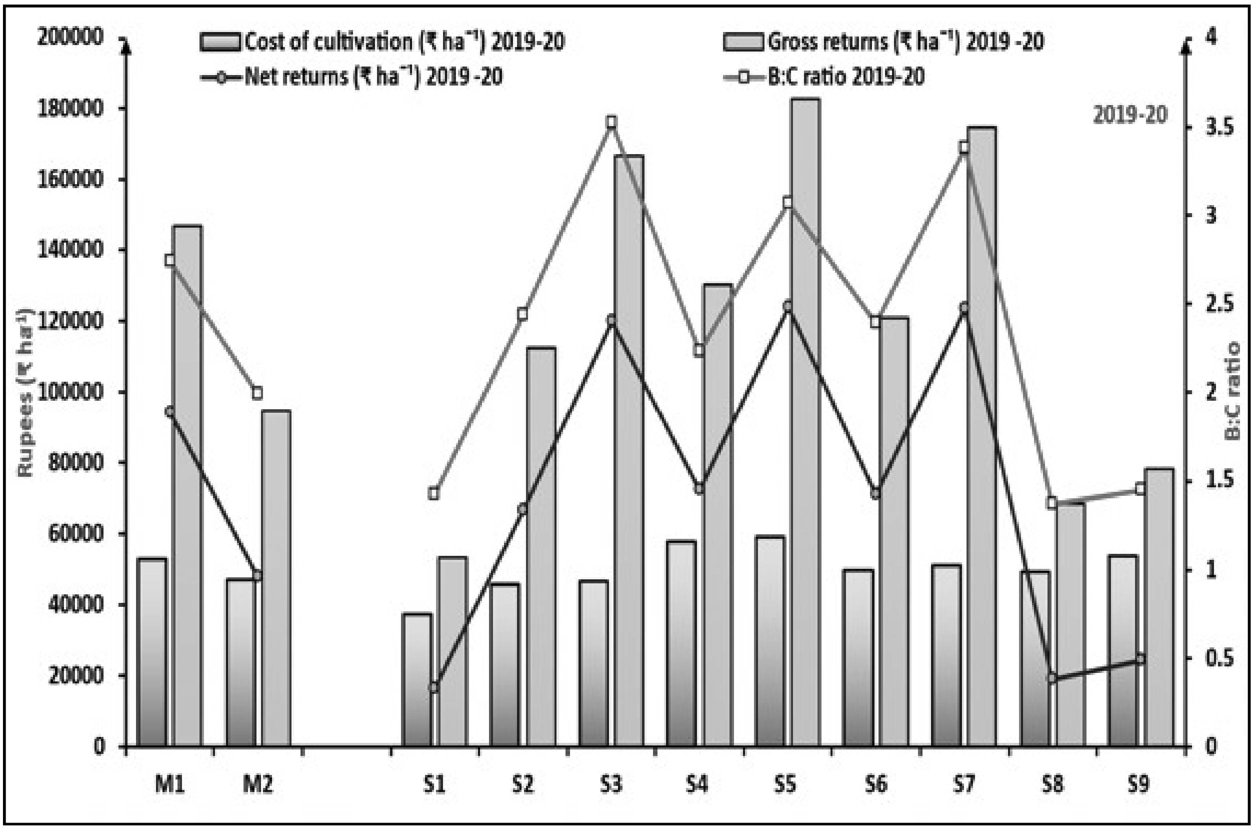

Figure 1. Economics of HDPS cotton influenced by Genotypes and Integrated Nutrient Management in 2019-20

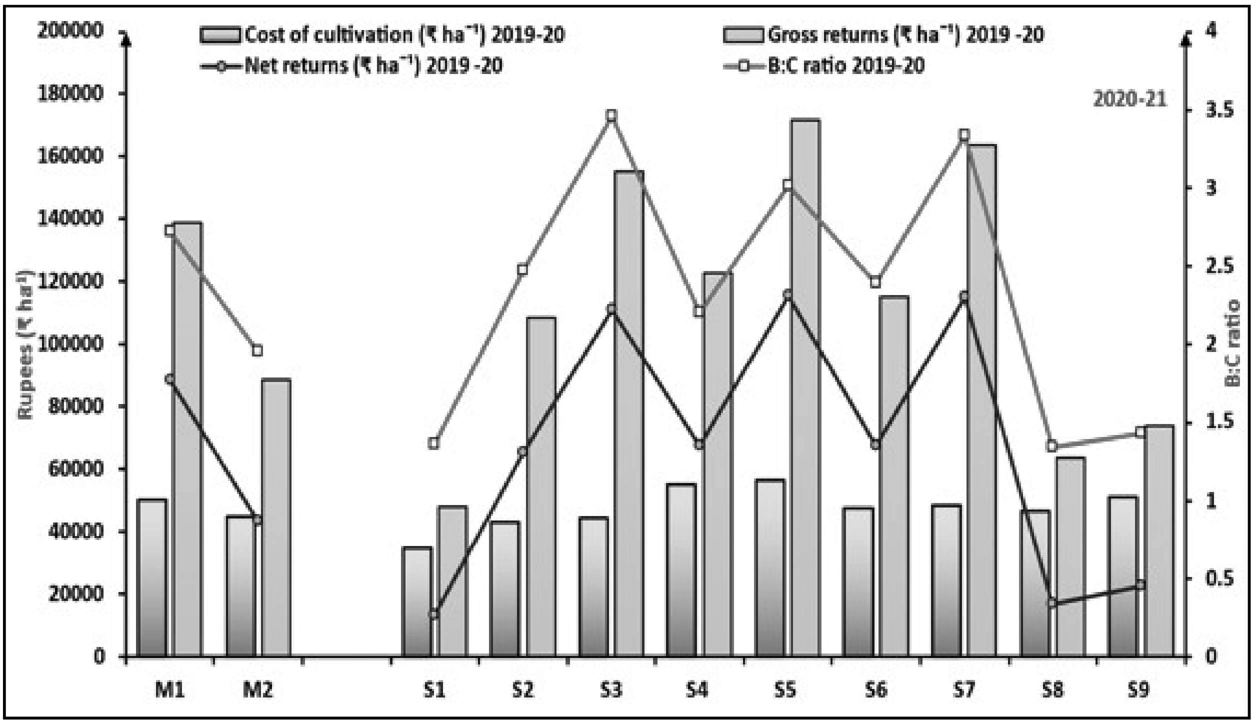

Figure 1a. Economics of HDPS cotton influenced by Genotypes and Integrated Nutrient Management in 2020-21

returns. The results are in conformity with the findings of Kumari *et al.* (2018), Vora *et al.* (2015) and Rudragouda *et al.* (2014).

B-C ratio

The B-C ratio varied across treatments due to differences in cultivation costs and gross returns due to genotypes and integrated nutrient management practices.

Genotypes had shown significant impact on B-C ratio in 2019-20 and 2020-21 years. *Bt,* KCH-14K59 BG II had highest B-C ratio (2.74 and 2.72), than non *Bt* ADB-542, (1.99 and 1.95). This was mainly due to higher seed cotton yield and higher gross returns. Similar results were obtained by Nagendar *et al.*(2017a), Joshi *et al.* (2011) and Sankaranarayanan *et al.* (2011).

Across all integrated nutrient management practices, (S_3) 100% RDF had resulted in significantly higher B-C ratio of 3.52 and 3.46 equivalent with (S_7) 100 % RDF + Foliar spray of *Jeevamrutha* @ 5% at 15 days interval up to harvest (3.38 and 3.33), while, lowest B-C ratio (1.42 and 1.36) was recorded with No fertilizer *i.e.* $S_{1,}$ in *kharif* 2019-20 and 2020-21, respectively. Application of higher levels of nutrients resulted in higher gross and net returns, B:C ratio as compared to lower level of nutrients. Better supplement of nutrients increased plant uptake, higher yield and yield parameters which in turn increased benefit-cost ratio in S_3, and S_7 treatments. Findings corroborate results of Kumari *et al.* (2018), Rudragouda *et al.* (2014) and Vinayak *et al.* (2013).

Genotype and integrated nutrient management interaction regarding gross returns, net returns and B:C ratio was non-significant.

CONCLUSION

Finally, it can be concluded that Bt, KCH-14K59 BG II outperformed non-Bt ADB-542 in terms of lint yield, seed yield, stalk yield, gross income, net income, and B:C ratio. Among the integrated nutrient management practises, the application of 100% RDF + soil application of Jeevamrutha @ 500 L ha^{-1} at 15-day intervals until harvest (S_5) resulted the highest lint yield, seed yield, stalk yield, gross income, and net income. However, with 100% RDF, the maximum B:C ratio was recorded (S_3).

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Research Article
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EVALUATION OF PIGEONPEA GERMPLASM LINES FOR RESISTANCE AGAINST *FUSARIUM* WILT DISEASE INCITED BY *FUSARIUM UDUM*

T. RAJESHWAR REDDY[1], B. VIDYASAGAR[2], S. SANDEEP[1], G. UMA DEVI[1], S.N.C.V.L. PUSHPAVALLI[3], G. SRIDEVI[4], C. SUDHAKAR[2] and C. SUDHA RANI[2]

[1]Department of Plant Pathology, College of Agriculture, Rajendranagar, Hyderabad

[2]Agricultural Research Station, Tandur, Vikarabad

[3]Institute of Biotechnology, PJTSAU, Hyderabad

[4]AINP on Pesticide Residues, Rajendranagar, Hyderabad

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ABSTRACT

A study was conducted to evaluate one hundred and seventy two pigeonpea germplasm lines against fusarium wilt in wilt sick plot during *Kharif* 2019-20 and *Kharif* 2020-21 at Agriculture Research Station, Tandur. This experiment was laid out in randomized block design with two replications, wherein checks of ICP 2376 (Susceptible check) and ICPL 87119 (Resistant check) were planted after every five rows of the germplasm lines to ascertain the uniformity in disease incidence across the sick plot. Significant differences in disease incidence among pigeonpea germplasm lines were observed in both the years of screening. Based on disease reaction, the per cent disease incidence (PDI) was calculated and the germplasm lines were divided into one of three categories *i.e.*, Resistant (R), Moderately Resistant (MR) and Susceptible (S). The pooled analysis of consecutive two years *viz.*, *Kharif,* 2019-20 and *Kharif,* 2020-21 revealed that, out of 172 germplasm lines, 21 germplasm lines showed resistant reaction with 0-10% disease incidence, of which six lines were asymptomatic in expression. While, remaining 45 germplasm lines exhibited moderately resistant in reaction, with 11-30 per cent disease incidence. The other 106 germplasm lines showed susceptible reaction with incidence that was greater than 30 per cent.

Key words: Pigeonpea, Germplasm, Screening, Fusarium wilt disease.

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is one of the most widely grown food grain legumes in the semi-arid tropics of the world (Nene and Sheila, 1990). India is the center of origin and largest producer of pigeonpea in the world sharing approximately 70 per cent of the production with an area covering 74 per cent (Bohra *et al.* 2012). In Telangana, the pigeonpea crop is presently grown in 2.94 L ha area with production of 2.65 L tones and productivity of 900 kg ha^{-1} (Directorate of Economic and Statistics, 2020-21). The yield potential of pigeonpea cultivars is not being realized owing to several biotic and abiotic constraints. The crop suffers from abiotic (e.g., drought, salinity and water-logging) and biotic (e.g., diseases like fusarium wilt, sterility mosaic and pod borer insects) stresses. Among biotic stresses, fusarium wilt (FW) caused by *Fusarium udum* is a major constraint for limiting pigeonpea production in all pigeonpea growing areas (Jain and Reddy 1995; Gwata *et al.* 2006). The disease symptoms appear at flowering to podding stage of the crop. A purple band extending upwards from the base of the main stem is the most distinctive sign of fusarium wilt disease. Browning or blackening of the stem tissue in the purple band region, as well as in the xylem, are further wilt symptoms seen when the main stem or main branches are split open. Before dying, infected plants show a variety of leaf symptoms, including loss of leaf turgidity, inter-veinal clearing, and chlorosis to a bright yellow colour (Reddy *et al.* 2012). However, symptoms also appear in at early developmental stages of crop growth. The symptoms at pre- flowering and podding stage results in 100 per cent yield loss, at maturity (67%), and at pre-harvest stage causing 30 per cent yield loss but sometimes symptoms also appear in 1–2 month old plants. The disease incidence increases in the ratoon and perennial crops (Reddy *et al.* 1993) and causes serious yield losses in susceptible cultivars. In Indian subcontinent the crop losses ranged from 16–47 per cent (Prasad *et al.* 2003) and wilt incidence is believed to have increased significantly over the time (Gwata *et al.* 2006). The repeated use of susceptible varieties is a major factor causing increased wilt disease incidence in this crop. The pathogen is both soil and seed borne in nature. The fungus survives in the soil as chlamydospores in diseased plant debris without

Email: rajeshwar.talakanti@gmail.com

losing viability up to six years even in the absence of the host plants (Haware *et al.*, 1996). Among the different available options for the management, chemical control of wilt disease is not much effective and economical because the pathogen is soil and seed-borne in nature and difficult to eradicate. The use of resistant cultivars to control wilt is the best and the cheapest method. Hence, the present study was carried out with an objective to screen the pigeonpea genotypes against fusarium wilt disease to identify the resistant sources.

MATERIAL AND METHODS

One hundred and seventy two pigeonpea germplasm lines were collected from Agricultural Research Station, Tandur, Telangana State were evaluated for fusarium wilt disease in wilt sick plot developed at Agricultural Research Station, Tandur during *Kharif* 2019-20 and 2020-21 crop seasons. Each entry was planted in a single row of 4 m length with spacing of 100 cm between rows and 20 cm between hills. A susceptible check ICP-2376 and resistant check ICPL-87119 were planted after every five rows to ascertain uniformity in disease incidence across the sick plot. The trial was conducted in randomized block design (RBD) with two replications. The standard cultural practices were followed. The per cent mortality due to wilt disease incidence was recorded from after 60 days sowing at an interval of 30 days up to 180 days. The plants exhibiting wilt disease as designated as susceptible while the one without wilt disease was designated as resistant. The wilt disease incidence was recorded as PDI [(Number of wilted plants/total number of plants) x 100] as per Mayee and Datar (1986). For recording the disease intensity under wilt sick plot conditions, AICRP scale was adopted for evaluating the pigeonpea germplasm against wilt disease incidence (Table 2). The arc sine transformed values of per cent incidence of germplasm lines were used for analysis of variance (ANOVA) using the INDOSTAT. The ANOVA s were obtained in terms of block and germplasm effects, considering the replications as random and germplasm as fixed. For combining data across two years, F test for homogeneity of error variance was done and found non significant. Therefore, data from the two years were pooled and ANOVA was performed using a mixed model considering the years as random and germplasm as fixed. The significance of main effects, year, germplasm lines and their interactions were tested against residual mean squares.

RESULTS AND DISCUSSION

A total of 172 germplasm lines were screened for resistance to the Fusarium wilt disease at the ARS Tandur Fusarium wilt sick plot during the *kharif*, 2019 and 2020. The findings of this study showed that there was a significant variation in disease incidence among pigeonpea germplasm lines in both the years of screening (Table 1). In accordance with the type of disease reaction they exhibited, the germplasm lines were divided into one of three distinct categories.

During the first year of screening, Out of 172 germplasm lines screened 27 lines exhibited resistant reaction, with disease incidence was ranged from 0 to 10 per cent. Whereas, 44 germplasm lines recorded a moderately resistant in reaction with 11-30 per cent disease incidence. The other remaining 101 germplasm lines showed susceptible in reaction, with greater than 30 per cent disease incidence (Figure 1).

In *kharif* 2020-21 also, out of 172 germplasm lines screened, 26 germplasm lines recorded resistant reaction with 0-10 per cent disease incidence and 43 germplasm lines showed moderately resistant reaction, with disease incidence of 11-30 per cent and the remaining 103 germplasm lines showed susceptible reaction, with an incidence of more than 30 per cent (Figure 1).

In addition, data from two years were pooled and found that the mean Fusarium wilt incidence among germplasm lines was varied from 0 to 98.68 per cent. The wilt sick plot had showed higher disease pressure, as determined by the higher mean disease incidence of 96.25 per cent in the susceptible check. The findings of the analysis of variance (ANOVA) showed that there was a significant (Pd”0.005) variation in the Fusarium wilt disease resistance among the 172 germplasm lines in both years of evaluation as well as in the pooled data from both years. This was true for both the individual germplasm lines and the combined data from both years. The interaction between year and line for the incidence of Fusarium wilt disease was not significant when the data from both years were pooled together. The mean square variance for the germplasm line was quite high, which indicates that

Table 1. Reaction of pigeonpea germplasm against *Fusarium* wilt disease at ARS, Tandur in sick plot during *Kharif* 2019-20 and *Kharif* 2020- 21

S. No	Germplasm lines	[a]Wilt incidence (%)		
		***Kharif* 2019-20**	***Kharif* 2020-21**	**Pooled**
1	TDRG-229	48.53 (44.16)	45.96 (42.69)	47.24 (43.42)
2	TDRG-230	59.41 (50.43)	72.12 (58.13)	65.76 (54.19)
3	TDRG-231	61.12 (51.43)	65.69 (54.15)	63.41 (52.78)
4	TDRG-232	12.92 (21.06)	10.48 (18.89)	11.70 (20.00)
5	TDRG-233	0.00 (0.00)	4.17 (11.78)	2.08 (8.30)
6	TDRG-234	75.74 (60.49)	80.56 (63.84)	78.15 (62.13)
7	TDRG-235	34.54 (36.00)	33.40 (35.31)	33.97 (35.65)
8	TDRG-236	3.85 (11.31)	6.46 (14.72)	5.15 (13.12)
9	TDRG-237	53.32 (46.91)	55.90 (48.39)	54.61 (47.65)
10	TDRG-238	43.33 (41.17)	42.26 (40.55)	42.80 (40.86)
11	TDRG-239	13.89 (21.88)	14.97 (22.77)	14.43 (22.33)
12	TDRG-240	32.46 (34.73)	28.72 (32.41)	30.59 (33.58)
13	TDRG-241	3.85 (11.31)	7.29 (15.67)	5.57 (13.65)
14	TDRG-242	91.18 (72.73)	94.59 (76.56)	92.88 (74.53)
15	TDRG-243	53.57 (47.05)	55.05 (47.90)	54.31 (47.48)
16	TDRG-244	6.70 (15.00)	2.78 (9.59)	4.74 (12.57)
17	TDRG-245	94.59 (76.56)	89.52 (71.12)	92.06 (73.64)
18	TDRG-246	33.02 (35.07)	29.95 (33.18)	31.48 (34.13)
19	TDRG-247	30.63 (33.60)	41.18 (39.92)	35.90 (36.81)
20	TDRG-248	71.22 (57.56)	74.90 (59.94)	73.06 (58.74)
21	TDRG-249	94.99 (77.07)	90.97 (72.52)	92.98 (74.64)
22	TDRG-250	48.53 (44.16)	48.33 (44.05)	48.43 (44.10)
23	TDRG-251	67.92 (55.50)	76.11 (60.75)	72.01 (58.07)
24	TDRG-252	35.50 (36.58)	34.31 (35.86)	34.91 (36.22)
25	TDRG-253	54.89 (47.81)	52.27 (46.31)	53.58 (47.06)
26	TDRG-254	42.93 (40.94)	48.33 (44.05)	45.63 (42.50)
27	TDRG-255	2.78 (9.59)	5.41 (13.45)	4.09 (11.67)
28	TDRG-256	8.83 (17.29)	12.50 (20.71)	10.67 (19.06)
29	TDRG-257	15.26 (22.99)	19.12 (25.93)	17.19 (24.50)
30	TDRG-258	6.27 (14.51)	6.46 (14.72)	6.37 (14.62)
31	TDRG-259	32.05 (34.48)	34.31 (35.86)	33.18 (35.18)
32	TDRG-260	41.43 (40.07)	43.92 (41.51)	42.68 (40.79)
33	TDRG-261	7.29 (15.67)	14.84 (22.66)	11.06 (19.43)
34	TDRG-262	63.16 (52.64)	59.03 (50.20)	61.10 (51.41)
35	TDRG-263	32.46 (34.73)	31.93 (34.41)	32.19 (34.57)

S. No	Germplasm lines	[a]Wilt incidence (%)		
		Kharif 2019-20	*Kharif* 2020-21	Pooled
36	TDRG-264	50.00 (45.00)	44.92 (42.09)	47.46 (43.55)
37	TDRG-265	55.36 (48.08)	65.48 (54.02)	60.42 (51.02)
38	TDRG-266	74.34 (59.57)	75.29 (60.20)	74.82 (59.88)
39	TDRG-267	33.33 (35.27)	34.85 (36.18)	34.09 (35.73)
40	TDRG-268	13.81 (21.82)	17.07 (24.40)	15.44 (23.14)
41	TDRG-269	6.27 (14.51)	9.45 (17.91)	7.86 (16.29)
42	TDRG-270	30.95 (33.81)	36.88 (37.40)	33.92 (35.62)
43	TDRG-271	45.00 (42.13)	42.22 (40.53)	43.61 (41.33)
44	TDRG-272	1.92 (7.97)	3.57 (10.89)	2.75 (9.54)
45	TDRG-273	17.27 (24.56)	10.48 (18.89)	13.87 (21.87)
46	TDRG-274	24.29 (29.53)	22.48 (28.30)	23.38 (28.92)
47	TDRG-275	15.48 (23.17)	18.82 (25.71)	17.15 (24.47)
48	TDRG-276	68.32 (55.75)	70.18 (56.90)	69.25 (56.33)
49	TDRG-277	36.40 (37.11)	40.59 (39.58)	38.49 (38.35)
50	TDRG-278	10.96 (19.34)	10.71 (19.11)	10.84 (19.22)
51	TDRG-279	20.00 (26.57)	26.67 (31.09)	23.33 (28.89)
52	TDRG-280	5.32 (13.34)	2.50 (9.10)	3.91 (11.41)
53	TDRG-281	66.76 (54.80)	59.02 (50.20)	62.89 (52.47)
54	TDRG-282	74.90 (59.94)	68.75 (56.02)	71.83 (57.95)
55	TDRG-283	42.02 (40.41)	42.81 (40.87)	42.41 (40.64)
56	TDRG-284	48.08 (43.90)	49.85 (44.91)	48.96 (44.41)
57	TDRG-285	48.53 (44.16)	55.42 (48.11)	51.97 (46.13)
58	TDRG-286	100.00 (90.01)	92.86 (74.50)	96.43 (79.11)
59	TDRG-287	73.61 (59.09)	82.31 (65.13)	77.96 (62.00)
60	TDRG-288	34.52 (35.99)	33.27 (35.23)	33.90 (35.61)
61	TDRG-289	46.43 (42.96)	40.08 (39.28)	43.25 (41.13)
62	TDRG-290	54.70 (47.70)	50.00 (45.00)	52.35 (46.35)
63	TDRG-291	71.67 (57.84)	62.91 (52.49)	67.29 (55.12)
64	TDRG-292	72.79 (58.57)	70.09 (56.85)	71.44 (57.70)
65	TDRG-293	54.32 (47.48)	58.17 (49.71)	56.24 (48.59)
66	TDRG-294	65.69 (54.15)	62.15 (52.04)	63.92 (53.09)
67	TDRG-295	69.92 (56.75)	71.96 (58.03)	70.94 (57.39)
68	TDRG-296	78.95 (62.69)	76.13 (60.76)	77.54 (61.71)
69	TDRG-297	80.36 (63.70)	85.91 (67.96)	83.13 (65.76)
70	TDRG-298	68.83 (56.06)	73.53 (59.04)	71.18 (57.53)
71	TDRG-299	59.97 (50.75)	63.33 (52.74)	61.65 (51.74)

S. No	Germplasm lines	[a]Wilt incidence (%)		
		Kharif 2019-20	*Kharif* 2020-21	Pooled
72	TDRG-300	74.18 (59.47)	76.97 (61.33)	75.58 (60.39)
73	TDRG-301	64.58 (53.48)	68.07 (55.60)	66.33 (54.53)
74	TDRG-302	70.81 (57.30)	76.79 (61.20)	73.80 (59.22)
75	TDRG-303	96.88 (79.82)	96.67 (79.49)	96.77 (79.65)
76	TDRG-304	30.09 (33.27)	34.38 (35.90)	32.23 (34.60)
77	TDRG-305	48.33 (44.05)	47.22 (43.41)	47.78 (43.73)
78	TDRG-307	44.76 (42.00)	42.81 (40.87)	43.79 (41.43)
79	TDRG-308	28.17 (32.06)	32.71 (34.89)	30.44 (33.49)
80	TDRG-309	46.26 (42.86)	41.05 (39.85)	43.65 (41.36)
81	TDRG-310	7.49 (15.88)	16.67 (24.10)	12.08 (20.34)
82	TDRG-311	63.33 (52.74)	53.59 (47.06)	58.46 (49.87)
83	TDRG-312	31.67 (34.25)	32.23 (34.59)	31.95 (34.42)
84	TDRG-313	46.43 (42.96)	41.44 (40.07)	43.93 (41.52)
85	TDRG-314	31.75 (34.30)	36.11 (36.94)	33.93 (35.63)
86	TDRG-315	42.46 (40.67)	39.80 (39.12)	41.13 (39.90)
87	PRG 176 x ICPL 20096 (BC_1F_1)	97.22 (80.41)	92.43 (74.03)	94.83 (76.86)
88	BC_1F_1 PRG 176 x ICPL 20096	100.00 (90.01)	97.37 (80.67)	98.68 (83.42)
89	TDRG-169	31.25 (33.99)	34.52 (35.98)	32.88 (34.99)
90	TDRG-177	17.93 (25.05)	20.63 (27.02)	19.28 (26.05)
91	TDRG-172	47.30 (43.46)	48.91 (44.38)	48.11 (43.92)
92	TDRG-173	46.74 (43.13)	52.08 (46.20)	49.41 (44.67)
93	TDRG-170	42.56 (40.73)	48.08 (43.90)	45.32 (42.32)
94	TDRG-166	34.84 (36.18)	32.67 (34.86)	33.75 (35.52)
95	TDRG-179	30.00 (33.21)	38.10 (38.12)	34.05 (35.70)
96	TDRG-178	12.25 (20.49)	19.52 (26.22)	15.89 (23.49)
97	TDRG-176	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
98	TDRG-162	86.97 (68.85)	82.00 (64.90)	84.49 (66.81)
99	TDRG-180	30.50 (33.52)	26.25 (30.82)	28.37 (32.19)
100	TDRG-165	38.82 (38.55)	44.00 (41.56)	41.41 (40.06)
101	TDRG-175	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
102	TDRG-167	10.60 (19.00)	13.69 (21.72)	12.14 (20.40)
103	TDRG-171	13.54 (21.59)	15.51 (23.20)	14.53 (22.41)
104	TDRG-193	32.05 (34.48)	34.49 (35.97)	33.27 (35.23)
105	TDRG-200	30.67 (33.63)	31.82 (34.34)	31.24 (33.99)
106	TDRG-187	40.83 (39.72)	35.63 (36.65)	38.23 (38.20)

S. No	Germplasm lines	[a]Wilt incidence (%)		
		Kharif 2019-20	*Kharif* 2020-21	Pooled
107	TDRG-75	46.03 (42.73)	45.83 (42.61)	45.93 (42.67)
108	TDRG-84	33.18 (35.17)	33.63 (35.45)	33.41 (35.31)
109	TDRG-110	16.00 (23.58)	18.33 (25.35)	17.17 (24.48)
110	TDRG-211	10.42 (18.83)	15.07 (22.85)	12.75 (20.92)
111	PRIL-B-14	10.17 (18.59)	12.55 (20.75)	11.36 (19.70)
112	TDRG-145	48.33 (44.04)	43.75 (41.41)	46.04 (42.73)
113	TDRG-121	33.24 (35.21)	54.17 (47.39)	43.70 (41.39)
114	TDRG-123	43.56 (41.30)	56.73 (48.87)	50.14 (45.09)
115	TDRG-127	35.52 (36.58)	32.87 (34.98)	34.19 (35.79)
116	PRIL-B-18	37.41 (37.71)	44.51 (41.85)	40.96 (39.79)
117	TDRG-122	28.74 (32.42)	36.84 (37.37)	32.79 (34.93)
118	TDRG-125	48.33 (44.05)	41.89 (40.33)	45.11 (42.20)
119	PRIL-B-39	34.85 (36.18)	30.79 (33.71)	32.82 (34.95)
120	TDRG-130	62.75 (52.39)	56.25 (48.59)	59.50 (50.48)
121	PRIL-B-37	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
122	PRIL-B-42	78.33 (62.26)	73.46 (59.00)	75.90 (60.60)
123	PRIL-B-19	38.75 (38.50)	34.48 (35.96)	36.61 (37.24)
124	TDRG-120	35.42 (36.52)	27.92 (31.90)	31.67 (34.25)
125	TDRG-126	12.22 (20.46)	12.69 (20.87)	12.46 (20.67)
126	PRIL-B-102	10.10 (18.53)	14.09 (22.05)	12.10 (20.35)
127	TDRG-114	7.18 (15.54)	18.61 (25.56)	12.90 (21.05)
128	PRIL-B-161	11.11 (19.47)	13.26 (21.35)	12.18 (20.43)
129	TDRG-212	0.00 (0.00)	2.27 (8.67)	1.14 (6.12)
130	TDRG-137	40.08 (39.28)	38.19 (38.17)	39.14 (38.73)
131	TDRG-211	15.63 (23.29)	13.25 (21.35)	14.44 (22.33)
132	TDRG-212	5.44 (13.49)	3.33 (10.52)	4.39 (12.09)
133	TDRG-213	2.50 (9.10)	2.08 (8.30)	2.29 (8.71)
134	TDRG-141	0.00 (0.00)	2.38 (8.88)	1.19 (6.26)
135	TDRG-142	12.88 (21.03)	18.25 (25.29)	15.57 (23.24)
136	TDRG-216	10.26 (18.69)	22.18 (28.10)	16.22 (23.75)
137	TDRG-217	9.81 (18.25)	15.04 (22.82)	12.42 (20.64)
138	TDRG-135	10.32 (18.74)	11.28 (19.63)	10.80 (19.19)
139	TDRG-134	11.21 (19.56)	11.15 (19.50)	11.18 (19.53)
140	TDRG-220	69.32 (56.37)	72.98 (58.68)	71.15 (57.52)
141	TDRG-221	0.00 (0.00)	5.32 (13.34)	2.66 (9.39)
142	TDRG-222	13.89 (21.88)	20.20 (26.71)	17.05 (24.39)

S. No	Germplasm lines	aWilt incidence (%)		
		Kharif 2019-20	*Kharif* 2020-21	Pooled
143	TDRG-223	2.94 (9.88)	2.94 (9.88)	2.94 (9.88)
144	TDRG-140	17.32 (24.60)	20.19 (26.70)	18.76 (25.67)
145	TDRG-133	19.05 (25.88)	15.97 (23.55)	17.51 (24.74)
146	TDRG-226	15.88 (23.49)	18.33 (25.35)	17.11 (24.43)
147	IL-9045	19.90 (26.50)	20.53 (26.94)	20.21 (26.72)
148	IL-45	19.05 (25.88)	15.76 (23.39)	17.40 (24.66)
149	IL-14815	10.23 (18.66)	12.50 (20.71)	11.37 (19.70)
150	IL-14722	15.07 (22.85)	10.00 (18.44)	12.54 (20.74)
151	IL-15049	10.43 (18.84)	10.63 (19.03)	10.53 (18.94)
152	IL-8860	13.81 (21.82)	9.72 (18.17)	11.77 (20.06)
153	ICP-8860	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
154	ICP-14722	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
155	ICP-7118	31.86 (34.36)	33.33 (35.27)	32.60 (34.82)
156	ICP-14421	15.97 (23.55)	15.26 (22.99)	15.61 (23.28)
157	ICP-11230	36.50 (37.17)	29.79 (33.08)	33.14 (35.15)
158	ICP-7119	47.50 (43.57)	45.59 (42.47)	46.54 (43.02)
159	ICP-9045	88.24 (69.95)	90.48 (72.03)	89.36 (70.96)
160	ICP-14976	62.28 (52.11)	56.35 (48.65)	59.31 (50.37)
161	ICP-11015	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
162	TDRG-220	29.17 (32.69)	31.02 (33.84)	30.09 (33.27)
163	TDRG-222	86.40 (68.37)	76.18 (60.79)	81.29 (64.38)
164	TDRG-221	62.50 (52.24)	55.56 (48.19)	59.03 (50.20)
165	TDRG-223	33.33 (35.27)	40.28 (39.40)	36.81 (37.35)
166	TDRG-224	31.25 (33.99)	33.48 (35.36)	32.37 (34.68)
167	TDRG-225	27.88 (31.88)	35.63 (36.65)	31.75 (34.30)
168	TDRG-160	9.43 (17.88)	17.14 (24.46)	13.29 (21.38)
169	TDRG-227	29.29 (32.77)	30.95 (33.81)	30.12 (33.29)
170	TDRG-228	17.36 (24.63)	18.75 (25.66)	18.06 (25.15)
171	TDRG-152	11.67 (19.97)	18.38 (25.39)	15.02 (22.81)
172	ICP 2376 (SC)	97.50 (80.91)	95.00 (77.08)	96.25 (78.84)
173	ICPL 87119 (RC)	2.27 (8.67)	0.00 (0.00)	1.14 (6.12)
	LSD (P = 0.05)b	7.49	9.87	6.26

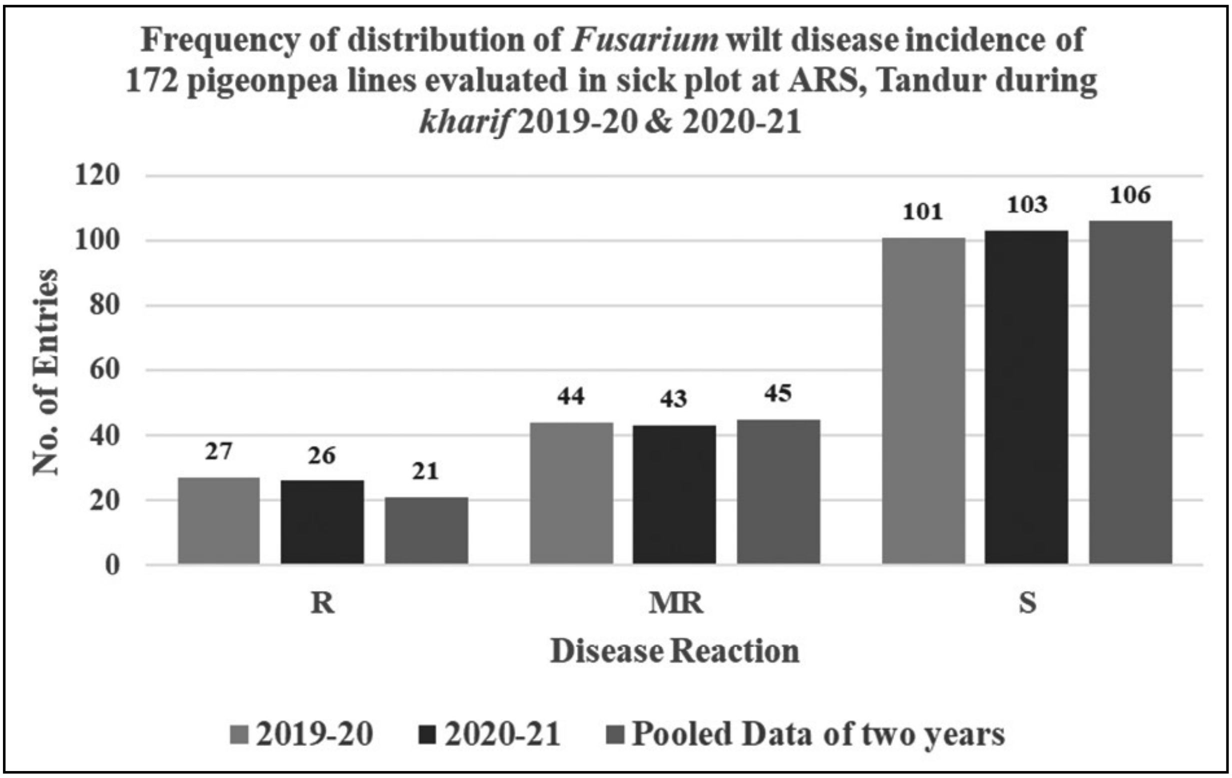
a Mean of two replications; b least significant difference

the test lines were the primary contributors to the differences in disease incidence. There was no discernible effect of years on the incidence of the disease, which suggests that the population of *Fusarium udum* in the sick plot was consistent throughout two years (Table 1).

Average disease incidence across both the years, 21 germplasm line *viz*., TDRG-233, TDRG-236,

		Mean Sum of Squares
Source of variation	**df**	**Fusarium wilt incidence**
Year (Y)	1	47.94
Germplasm (G)	173	1435.56**
Y X G	346	16.24
Year 2019		
Replication	1	50.95
Germplasm (G)	173	764.23**
Year 2020		
Replication	1	44.94
Germplasm (G)	173	687.56**

**Significant at Pd" 0.005



R- Resistant, MR- Moderately Resistant, S- Susceptible

Figure 1. Frequency of distribution of *Fusarium* wilt disease incidence of 172 pigeonpea lines evaluated in sick plot at ARS, Tandur during *kharif* 2019-20 & 2020-21

TDRG-241, TDRG-244, TDRG-255, TDRG-258, TDRG-269, TDRG-272, TDRG-280, TDRG-176, TDRG-175, PRIL-B-37, TDRG-212, TDRG-213, TDRG-141, TDRG-221, TDRG-223, ICP-8860, ICP-14722 and ICP-11015) germplasm lines showed resistant reaction with 0-10 per cent disease incidence, of which 6 lines (TDRG-176, TDRG-175, PRIL-B-37, ICP-8860, ICP-14722 and ICP-11015) were asymptomatic in disease expression. Results in Table 2 indicated that 45 germplasm lines were moderately resistant in reaction, with 11-30 per cent disease incidence, while, 106 germplasm lines showed susceptible reaction with more than 30 per cent disease incidence.

Table 2. Reaction of pigeonpea germplasm against Fusarium wilt at ARS, Tandur sick plot during *Kharif* 2019-20 and *Kharif* 2020- 21

Disease scale	Particulars	Reaction	Germplasm	Number of Germplasm
1	0-10% plants wilted – (Resistant)	R	TDRG-233, TDRG-236, TDRG-241, TDRG-244, TDRG-255, TDRG-258, TDRG-269, TDRG-272, TDRG-280, TDRG-176, TDRG-175, PRIL-B-37, TDRG-212, TDRG-213, TDRG-141, TDRG-221, TDRG-223, ICP-8860, ICP-14722 and ICP-11015 + ICPL 87119 (RC)	21
2	10.10-30% plants wilted – (Moderately Resistant)	MR	TDRG-232, TDRG-239, TDRG-256, TDRG-257, TDRG-261, TDRG-268, TDRG-2733, TDRG-274, TDRG-275, TDRG-278, TDRG-279, TDRG-309, TDRG-177, TDRG-178, TDRG-180, TDRG-167, TDRG-171, TDRG-110, TDRG-211, PRIL-B-14, TDRG-126, PRIL-B-102, TDRG-114, PRIL-B-161, TDRG-142, TDRG-216, TDRG-217, TDRG-135, TDRG-134, TDRG-222, TDRG-140, TDRG-133, TDRG-226, IL-9045, IL-45, IL-14815, IL-14722, IL-15049, IL-8860, ICP-14421, TDRG-220, TDRG-160, TDRG-228 and TDRG-152	45
3	>30 % plants wilted – (Susceptible)	S	TDRG-229, TDRG-230, TDRG-231, TDRG-234, TDRG-235, TDRG-237, TDRG-238, TDRG-240, TDRG-242, TDRG-243, TDRG-245, TDRG-246, TDRG-247, TDRG-248, TDRG-249, TDRG-250, TDRG-251, TDRG-252, TDRG-253, TDRG-254, TDRG-259, TDRG-260, TDRG-262, TDRG-263, TDRG-264, TDRG-265, TDRG-266, TDRG-267, TDRG-270, TDRG-271, TDRG-276, TDRG-277, TDRG-281, TDRG-282, TDRG-283, TDRG-284, TDRG-285, TDRG-286, TDRG-287, TDRG-288, TDRG-289, TDRG-290, TDRG-291, TDRG-292, TDRG-293, TDRG-294, TDRG-295, TDRG-296, TDRG-297, TDRG-298, TDRG-299, TDRG-300, TDRG-301, TDRG-302, TDRG-303, TDRG-304, TDRG-305, TDRG-306, TDRG-307, TDRG-308, TDRG-310, TDRG-311, TDRG-312, TDRG-313, TDRG-314, TDRG-315, PRG 176 x ICPL 20096 (BC1F1), BC1F1 PRG 176 x ICPL 20096, TDRG-169, TDRG-172, TDRG-173, TDRG-170, TDRG-166, TDRG-179, TDRG-162, TDRG-165, TDRG-193, TDRG-200, TDRG-187, TDRG-75, TDRG-84, TDRG-145, TDRG-121, TDRG-123, TDRG-127, PRIL-B-18, TDRG-122, TDRG-125, PRIL-B-39, TDRG-130, PRIL-B-42, PRIL-B-19, TDRG-120, TDRG-137, TDRG-220, ICP-7118, ICP-11230, ICP-7119, ICP-9045, ICP-14976, TDRG-222, TDRG-221, TDRG-223, TDRG-224, TDRG-225 and TDRG-227+ ICP 2376 (SC)	106
Total				172

This study confirms that there was a significant variation in disease incidence existed among the pigeonpea germplasm lines screened. Choudhary (2010) found that IPA 204, a long duration entry was resistant to fusarium wilt disease. Similarly, Choudhary and Nadarajan (2011) recorded that BDN 1, BDN 2, C 11, ICPL 87119, BSMR 736, TS 3R, WRP 1 and DA 11 entries were resistant to wilt disease. Singh *et al.,* (2011) also reported that IPA 16F, IPA 8F, IPA 9F and IPA 12F were resistant to wilt disease. Sharma *et al.* (2012) and Sharma and Pande (2011) also observed that 18 genotypes *viz.*, ICP 6739, ICP 8860, ICP 11015, ICP 13304, ICP 14638, ICP 14819, ICP 7903, ICP 12031, ICP 12059, ICP 12841, ICP 13257, ICP 13258, ICP 12771, ICP12775, ICP 12775, ICP7991, ICP 13618, ICP14291 and ICP 15137 as new source of resistance to *Fusarium* wilt disease of pigeonpea. Similarly, Jaggal *et al.,* (2014) sshowed that 39 accessions were resistant to wilt disease. Pawar *et al.,* (2015) reported that two germplasm lines *viz.*, ICP-7088 and ICP-8863 were found resistant against wilt disease. Subash *et al.* (2019) reported that, twelve germplasm lines *viz.*, AL 1932, BRG 5, CRG 2013-10, GRG 82, GRGK 1, ICP 8863, ICPHL 4989-7, KA 12-3, PT 257, PT 307-1, WRG 293 and ICP 8863 were found resistant to *Fusarium* wilt disease. Further, Shivalingappa *et al.* (2021) conducted demonstrations for the assessment of promising varieties of pigeonpea against *Fusarium* wilt disease with farmers participation in Vijayapur district of Karnataka for two years *i.e.*, during 2019-20 and 2020-21. The results indicated that the per cent disease incidence of *Fusarium* wilt was severe in BDN-711 (36.00 PDI) and lower in GRG 811 (05.60 PDI).

Fusarium wilt was observed in up to 36.3 per cent in Malawi, Africa, in 1980 (Kannaiyan *et al.*, 1981), but the introduction of resistant variety ICP 9145 reduce the wilt incidence upto 4 per cent by the year 1991. This demonstrated the importance of resistant cultivars in reducing the disease severity. (Babu *et al.,* 1992; Reddy *et al.*, 1993; Saka *et al.*, 1995 and Subramanyam *et al.*, 1992). After the release of pigeonpea wilt resistant variety ICP 8863 as "Maruthi" in the late 1980s, there was significant reduction in disease incidence in Karnataka state and occupies a large in area.

CONCLUSION

Screening of germplasm is essential to know the plasticity of the pathogen and also to develop resistant material towards the pathogen which is the only solution for combating the disease. In the present study 21 germplasm lines have been identified as resistant to *F. udum* and found resistant against *F. udum* consistently over two years under fusarium wilt sick plot conditions. Further, this resistant material will be utilized as donors in future breeding programme for incorporation of resistance in agronomically desirable high yielding varieties of pigeonpea.

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COMPARATIVE ECONOMICS AND CONSTRAINTS ANALYSIS OF COTTON GROWERS UNDER DIFFERENT FARMING SITUATIONS OF TELANGANA STATE

S. RADHA[1], K. SUHASINI[1], MD. ALIBABA[1], D. SRINIVASA REDDY[2] and D. SRINIVASA CHARY[3]

[1]Department of Agricultural Economics, College of Agriculture, PJTSAU, Rajendranagar

[2]Department of Agribusiness Management, College of Agriculture, PJTSAU, Rajendranagar

[3]Department of Statistics and Mathematics, College of Agriculture, PJTSAU, Rajendranagar

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ABSTRACT

Cotton the 'King of fibres' is the important commercial crop of Telangana state occupying an area of 23.48 lakh hectares with 30.42 lakh MT of production during the year 2020-21. The crop is mainly grown under rainfed condition in a wide range of soils like red loamy, deep black, chalka soil and dubba. Considering the different soil types and the irrigation availability, the costs and returns were computed for different farming situations *viz.*, FS-1 (Irrigated red soil), FS-2 (Rainfed red soil), FS-3 (Chalka soil), FS-4 (Irrigated black soil) and FS-5 (Rainfed black soil). Further, the constraints were analysed based on the primary data collected from 350 cotton growing farmers from 16 villages belonging to eight mandals of districts viz., Nalgonda, Nagarkurnool, Adilabad and Sangareddy during the year 2020-21. The comparison done using tabular analysis inferred that, cotton cultivation was highly profitable in FS-4 with net returns of (₹ 64773.67) followed by FS-1 (₹ 48680.16), FS-5 (₹ 33483.70) and FS-2 (₹ 24441.86) while, in FS-3 it was a loss with negative net returns (₹-1310.70). Economically unviable cotton cultivation in FS-3 recommends for cultivation of other suitable crop viz., millets, pulses and ground nut. Further, constraint analysis inferred that, the crop suffered from pests and diseases infestation, inadequate /excess rainfall, labour scarcity, lack of infrastructure leading to low prices at the time of harvest and poor technical know-how. Hence, the study recommends developing resistant cotton hybrids. Adoption of mulching practices in rainfed cotton, timely and adequate irrigation via water saving techniques in irrigated cotton, better infrastructure and training programmes for dissemination of new technologies is much needed.

Key words: Cotton, Farming situations, Cost and returns, Net income, Constraints

Agriculture has been elixir for any economy to secure food and income security and Telangana is no exceptional with more than half of the work force being engaged and earning their living. Agriculture in the state is mainly dependent on rainfall. Based on the rainfall, soil type, climate etc., Telangana state is partitioned into three agroclimatic zones viz, Northern Telangana zone (Adilabad, Karimnagar and Nizambad), Central Telangana zone (Khammam, Medak and Warangal), Southern Telangana zone (Hyderabad, Nalgonda, Mahbubnagar and Rangareddy).

The soils in Telangana state are red gravelly soil, chalka soil, black cotton soil and deep red loamy soil. The major crops cultivated are Paddy, Cotton, Maize and Red gram occupying nearly 85 per cent of the cultivated area.

After paddy, cotton has been the predominantly grown crop of the state. It grows majorly under rainfed conditions on variety of soils. The crop usually grows in well drained soils and is highly sensitive to water logging (Bandyopadhyay *et al.*, 2007). In Telangana cotton is being grown under different farming situations *viz.*, FS-1 (Irrigated red soils), FS-2 (Rainfed red soil), FS-3 (Chalka soil), FS-4 (Irrigated black soil) and the FS-5 (Rainfed black soil). During the year 2020-21, cotton occupied an area of 23.48 lakh hectares (DES, 2020-21).

Telangana stands second in the area under cotton crop at all India level and produces nearly 20 per cent of country's cotton. The major districts producing cotton during the year 2019-20 were Nalgonda (2.73 lakh ha) followed by Nagarkurnool (1.42 lakh ha), Adilabad (1.40 lakh ha) and Sangareddy (1.40 lakh ha) (DES, 2020-21).

Irrigation projects taken up by Government of Telangana led to massive rise in paddy cultivation leading to excessive supply of paddy into the markets. To avoid the further expansion, Government recommended for crop diversification (Agriculture Action plan, 2022). Simultaneously, increasing global demand for cotton with higher market prices led to scaling up of area under cotton in the state as it is the cash crop (https://www.deccanchronicle.com). But, extended cultivation of cotton with the expectation of high returns

Email: radhashivappa19@gmail.com

and good yield across non-traditional area where the soil fertility is poor would enhance farmers risk. Because, less fertile soils affected the cotton yield quantity and quality leading to financial losses to the cotton growers (Zhang *et al.* 2018).

Hence, the current study was taken up to quantify and compare the costs and returns incurred by cotton growers across different farming situations identified and to analyze the constraints faced by them. Further, it tries to convey and convince farmers about growing cotton in more suitable areas for better crop growth and returns.

MATERIAL AND METHODS

Study area

The districts *viz.*, Nalgonda, Nagarkurnool, Sangareddy and Adilabad were purposively chosen for the study as they possessed highest area under cotton during 2019-20 and were bestowed with red and black soils. Nalgonda and Nagarkurnool belonged to Southern Telangana zone, Sangareddy- Central Telangana Zone and Adilabad to Northern Telangana Zone. Red soil type was dominant in Nalgonda (54 %) and Nagarkurnool (64 %) districts while black soil type was in Adilabad (87 %) and Sangareddy (55 %). Figure 1 depicts the area wise distribution of cotton crop along different districts during the year 2019-20 based on the DES statistics. Highest area under cotton crop was held by Adilabad, Nalgonda, Nagakurnool, Sangareddy, Khammam and Asifabad as indicated by dark green gradient and the least area was held by Jagtial, Nizambad, Mulugu and Wanaparthy districts as shown by light colour gradient.

For working out the comparative economics and analyzing the constraints under different farming situations the primary data was extensively collected from 350 farmers through personal interview with pretested schedule for the year 2020-21. The sample farmers were randomly selected from 16 villages belonging to eight purposively chosen mandals. Five different farming situations (FS) were identified for the study *viz.,* FS-1 (Irrigated red soil), FS-2 (Rainfed red soil), FS-3 (Chalka soil), FS-4 (Irrigated black soil) and the FS-5 (Rainfed black soil) for comparison. About, 70 farmers were interviewed under each situation and the necessary data on costs incurred towards crop cultivation was collected and the costs were estimated as per the concepts of Commission for Agricultural

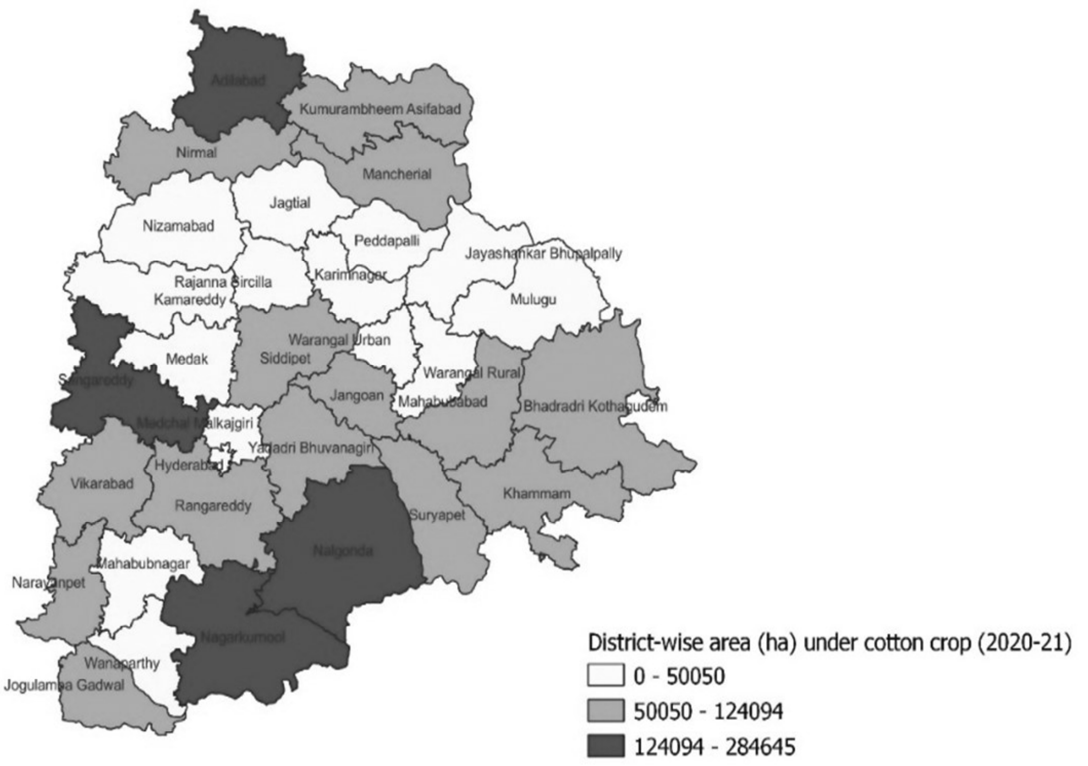

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Figure 1. Area under cotton crop (Hectares) in Telangana state during 2019-20

Costs and Prices (CACP) and comparison was made across different farming situations using tabular analysis.

The various cost concepts calculated include, Cost A1, Cost A2, Cost B1, Cost B2, Cost C1, Cost C2 and Cost C3.

Cost A1 was obtained by totalling the cost of hired human labour, machine labour (hired and owned), bullock power (hired and owned), manures (farm produced and purchased), fertilizers, seed (farm produced and purchased), plant protection chemicals, irrigation charges, interest on working capital, depreciation, land revenue and other miscellaneous expenses

Cost A2 =Cost A1 + rent paid for leased-in land

Cost B1 =Cost A1 + Imputed interest on value of owned capital assets (excluding land)

Cost B2 =Cost B1 + Imputed rental value of owned land (net of land revenue) + Rent paid for leased-in land

Cost C1 =Cost B1 + Imputed value of family labour

Cost C2 = Cost B2 + Imputed value of family labour

Cost C3 =Cost C2 + 10% of Cost C2 on account of managerial function performed by farmers

Farm business analysis

Gross income = Value of total output (main product + by product)

Farm business income = Gross income – Cost A1 or Cost A2

Family labour income = Gross income – Cost B2

Net income = Gross income – Cost C3

Farm investment income = Farm business income – Imputed value of family labour.

Return per rupee of expenditure = Present worth of gross return ÷ Present worth of gross cost

Garrett ranking technique

To rank the problems faced by sample respondents in production and marketing of cotton crop, Garrett's scoring technique was used. In this technique, the farmers were asked to rank the factors or problems and these ranks were converted into per cent position by using the formula.

$$\text{Percentage position} = \frac{100 \times (R_{ij} - 0.50)}{N_j}$$

Where,

R_{ij} = Ranking given to ith constraint by the jth individual.

N_j = Number of constraints ranked by the jth individual.

By referring to the Garrett's table, the percent positions worked out were converted into scores. The scores for each problem were added to get total score and the mean values were obtained. Constraints were ranked in the descending order of the mean scores.

RESULTS AND DISCUSSION

District wise trends in the area under cotton crop for past 30 years (1990-2020) was plotted in Figure 2 and it was observed that there was stagnant growth in the area under cotton prior to introduction of Bt-cotton in all districts. Post introduction of Bt-cotton there was rapid rise in the area under cotton in Adilabad, Nalgonda, Mahbubnagar and Warangal. In districts of Medak, Khmmam and Rangareddy there was steady and gradual increase in crop acreage. The results were supported by the review study of Shah (2012). While there was no change in the area under Nizambad even after introduction of Bt-cotton because paddy, sugarcane and turmeric were the major crops of district (District profile, 2017).

Highest area under cotton crop was observed in FS-5 (23.60 %) followed by FS-2 (22.32 %), FS-4 (20.97 %), FS-1 (19.33 %) and FS-3 (13.78 %) as presented in Table 1. It can be clearly observed that the cotton crop in the state is cultivated widely under rainfed situations rather than irrigated conditions.

Cost of cultivation of cotton crop

The costs and returns of cotton crop under different farming situations is furnished in Table 2. Appraisal of costs across the situations revealed that, human labour cost was the major variable across all the situations followed by fertilizers and plant protection chemicals. For the pooled sample, human labour contributed nearly 33 per cent to the total cost followed by fertilizers (11.47 %), plant protection chemicals (10.66 %) and machine labour (9.71 %). Cost of human labour was highest because the cotton picking was

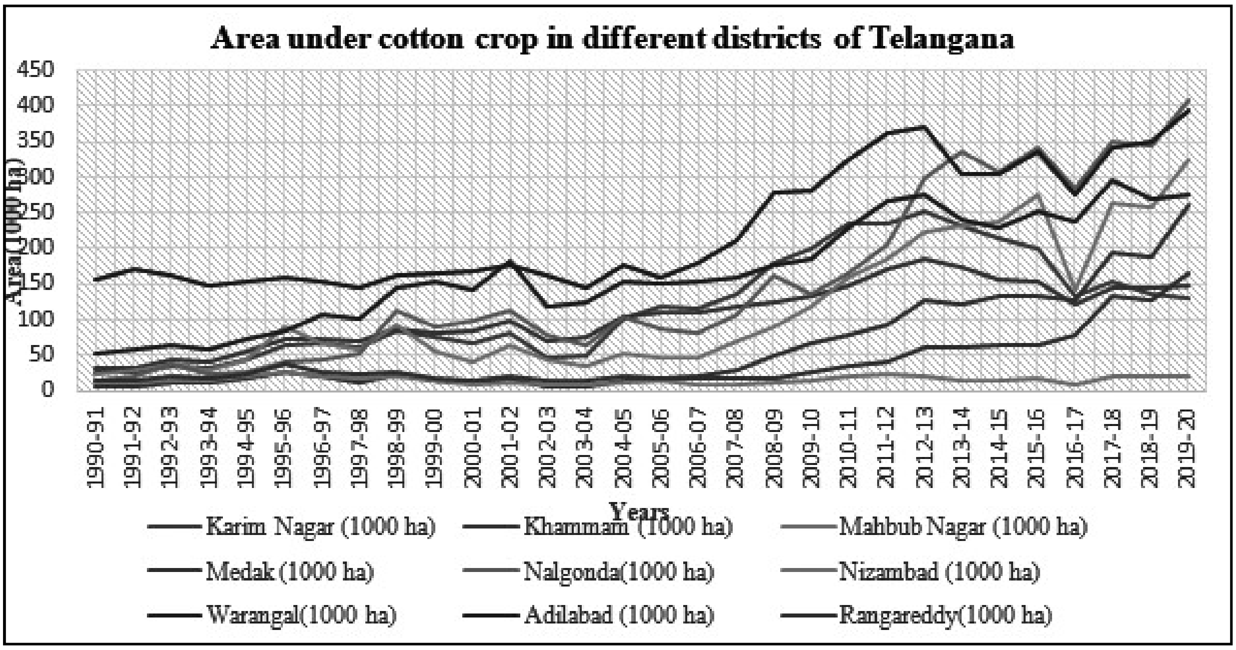


Figure 2. Area under cotton crop in erstwhile districts of Telangana (1990-2020)

Table 1. Area under cotton crop under different farming situations in sample farms

Farming situation	Area (Hectares)
Irrigated red soil (FS-1)	104.45 (19.33)
Rainfed red soil (FS-2)	120.65 (22.32)
Chalka soil (FS-3)	74.49 (13.78)
Irrigated black soil (FS-4)	113.36 (20.97)
Rainfed black soil (FS-5)	127.53 (23.60)
Total	540.48 (100.00)

Note: Figures in the parentheses indicate percentage to total

labourious. The cost of machine labour was higher in FS-4(₹ 9606. 59) and FS-5 (₹ 9307.29) in comparison to other farming situations because the black soils required more machine hours than the red soils. Increased pesticides cost was seen in FS-4 and FS-1 because lush green cotton crop in these situations allured more pest, disease and weed growth leading to higher use of plant protection chemicals. (Tippeswamy *et al.*, 2011).

Comparison of yields across different farming situations deduced that the yield of cotton was highest in FS-4 (27.79 Qtl/ ha) and fetched higher price (₹ 5800.61/quintal) due to good fibre quality as per information provided by farmers during interaction. Also, return per rupee of expenditure was highest in FS-4 (1.68), while it was lowest in the FS-3 with 0.98 because of the low yield due to poor water holding ability and lower nutrients in the soil. The results were supported by the study conducted by Satish and Reddy (2018) where black soils (vertisols) had higher seed cotton yield than the red soils (alfisols) due to better uptake of nutrients and water holding capacity.

Table 2. Comparative economics of cotton crop under different farming situations (₹ /ha)

Particulars	FS-1	FS-2	FS-3	FS-4	FS-5	Pooled
Operational cost						
Human labour	31051.39 (34.40)	28575.76 (34.40)	20791.38 (32.51)	32464.58 (33.67)	29540.47 (33.58)	28598.21 (33.47)
Bullock labour	5070.71 (5.62)	4861.66 (5.85)	3768.11 (5.89)	5626.62 (5.84)	4959.16 (5.64)	4890.35 (5.72)
Tractor power	7044.66 (7.80)	7762.33 (9.35)	7317.50 (11.44)	9606.59 (9.96)	9307.29 (10.58)	8297.45 (9.71)
Seeds	4574.44 (5.07)	4550.44 (5.48)	4664.03 (7.29)	4464.58 (4.63)	4733.33 (5.38)	4631.45 (5.42)
FYM	4498.21 (4.98)	4533.50 (5.46)	1081.50 (1.69)	4959.16 (5.14)	4551.14 (5.17)	3967.34 (4.64)
Fertilizers	9893.74 (10.96)	9887.75 (11.90)	9867.63 (15.43)	9606.59 (9.96)	9578.65 (10.89)	9801.57 (11.47)
Plant protection chemicals	9602.65 (10.64)	7799.55 (9.39)	7170.06 (11.21)	10164.40 (10.54)	9386.00 (10.67)	9108.91 (10.66)
Irrigation charges	348.12 (0.39)	0.00 (0.00)	0.00 (0.00)	543.34 (0.56)	0.00 (0.00)	211.23 (0.25)
Interest on working capital	2522.94 (2.80)	2378.98 (2.86)	1913.11 (2.99)	2710.25 (2.81)	2521.96 (2.87)	2489.12 (2.91)
Total operational cost	74606.86 (82.65)	70349.98 (84.70)	56573.32 (88.45)	80146.10 (83.12)	74578.00 (84.77)	71995.63 (84.25)
Fixed cost						
Rental value of owned land	12079.00 (13.38)	10902.57 (13.13)	5940.00 (9.29)	12814.00 (13.29)	11584.29 (13.17)	10998.12 (12.87)
Depreciation	845.21 (0.94)	789.00 (0.95)	650.89 (1.02)	812.42 (0.84)	727.12 (0.83)	773.23 (0.90)
Interest on fixed	2732.42 (3.03)	1017.79 (1.23)	799.09 (1.25)	2652.76 (2.75)	1089.14 (1.24)	1683.56 (1.97)
Total fixed cost	15656.63 (17.35)	12709.36 (15.30)	7389.98 (11.55)	16279.18 (16.88)	13400.55 (15.23)	13454.91 (15.75)
Total cost (Cost C2)	90263.49 (100.00)	83059.34 (100.00)	63963.30 (100.00)	96425.28 (100.00)	87978.55 (100.00)	85450.54 (100.00)
Main product (q)	24.21	19.27	11.73	27.79	21.61	21.18
Price(₹ /q)	5740.05	5579.84	5340.09	5800.61	5620.65	5560.33
Gross return	138943.7	107501.2	62652.61	161198.95	121462.25	117767.79
Net return	48680.16	24441.86	-1310.70	64773.67	33483.70	32317.25
Return per rupee of expenditure	1.54	1.29	0.98	1.68	1.38	1.39

Note: Figures in the parentheses indicate percentage to total
Source: Primary data

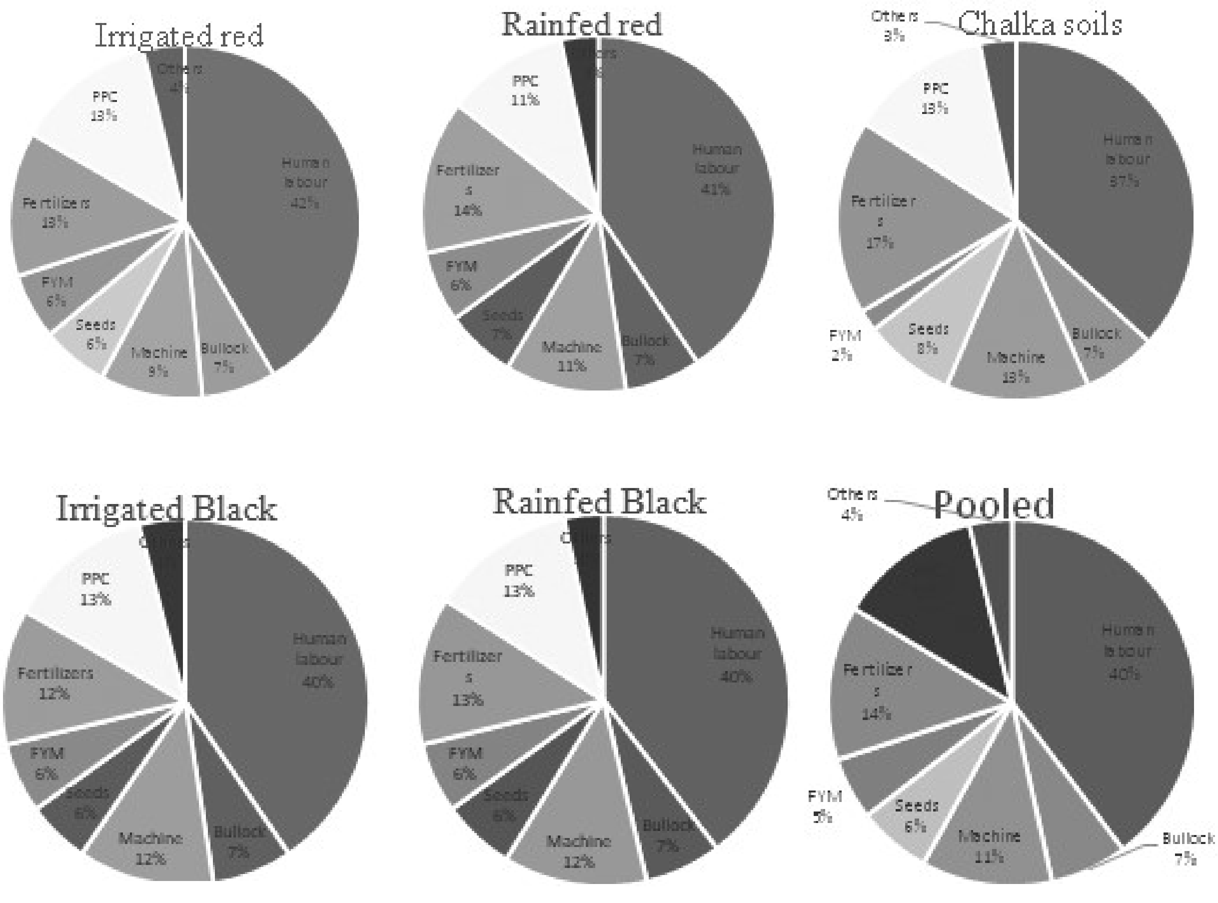
Ahlawat and Gangaiah (2010) also reported that optimum soil moisture status resulted in greater nutrient uptake, promoting the crop growth and yield attributes.

The pictorial representation of farming situation-wise breakup of operational costs (Figure 3) inferred that human labour was the major operational cost followed by fertilizers, plant protection chemicals and machine labour. Loganathan *et al.* (2009) reported that human labour was the major component of cost followed by fertilizers, machinery and seeds. The share of plant protection chemicals cost was less in their

and FS-3. For the pooled sample total cost was ₹ 85450.54 and the net returns was ₹ 32317.25.

Cost of cultivation

The costs were quantified for different farming situations and it was noted that C2 cost of cultivating cotton crop was highest in the FS-4 (₹ 96425.28) followed by FS-1 (₹ 90263.49), FS-5 (₹ 87978.55), FS-2 (₹ 83059.34) and FS-3 (₹ 63963.30) (Table 3.). Similar outcome was noticed in study conducted by Rohit *et al.* (2018) where farmers incurred more costs in irrigated cotton cultivation over rainfed.



Source: Primary data

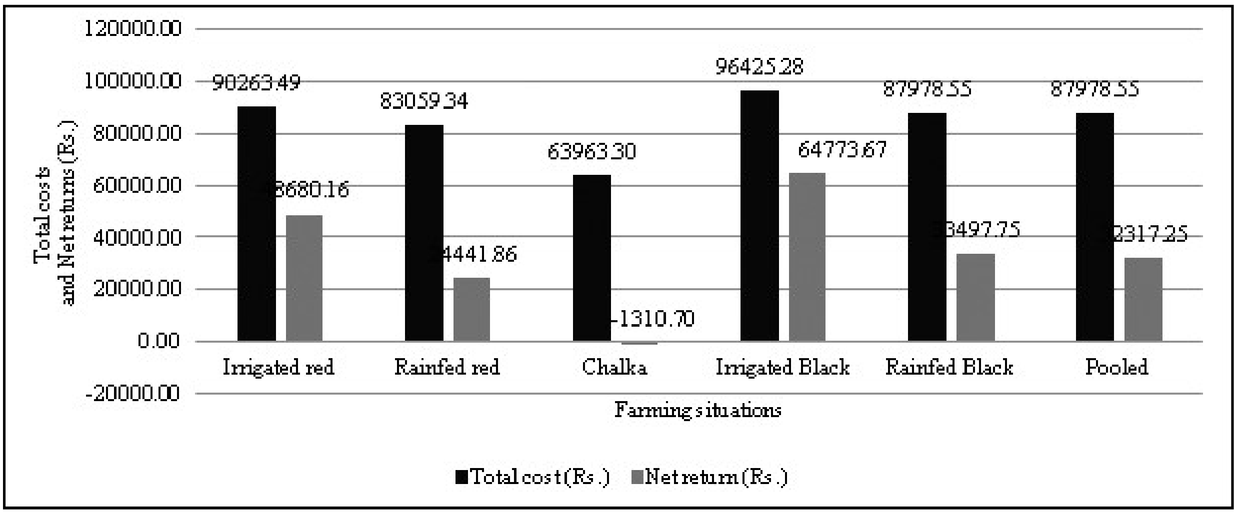
Figure 3. Farming situation wise breakup of operational cost

study, but in the current study it was higher, might be due to increased pest and disease attack.

The graphical representation of the total costs and net returns is presented in Figure 4. It disclosed that the total costs incurred and the net returns received was highest in FS-4 followed by FS-1, FS-5, FS-2

Farm business analysis

Farm business analysis for cotton reported in the Table 4. disclosed that, farmers growing cotton under FS-4 realized the highest net income (₹ 55131.14) whereas farmers who had cultivated cotton under FS-3 received the negative net income



Source: Primary data

Figure 4. Farming situation wise total cost and net returns

Table 3. Cost of cultivation of cotton crop as per cost concepts ([1] /ha)

Particulars	FS-1	FS-2	FS-3	FS-4	FS-5	Pooled
Cost A1	66661.71	62038.48	48014.01	72058.27	66105.02	63788.61
Cost B1	69394.13	63056.27	48813.1	74711.03	67194.16	65472.17
Cost B2	81473.13	73958.84	54753.1	87525.03	78778.45	76470.29
Cost C1	78184.49	72156.77	58023.30	83611.28	76394.26	74452.42
Cost C2	90263.49	83059.34	63963.30	96425.28	87978.55	85450.54
Cost C3	99289.84	91365.27	70359.63	106067.81	96776.40	93995.59

Source: Primary data

Table 4. Farm business analysis of cotton crop in the study area ([1] /ha)

Particulars	FS-1	FS-2	FS-3	FS-4	FS-5	Pooled
Gross Income	138943.65	107501.20	62652.61	161198.95	121476.30	117767.79
Farm Business Income	72281.94	45462.72	14638.59	89140.68	55371.28	53979.18
Family labour income	57470.52	33542.36	7899.50	73673.92	42697.85	41297.50
Net income	39653.81	16135.93	-7707.03	55131.14	24699.90	23772.20
Farm investment income	63491.94	36362.72	5428.59	80240.68	46171.28	44779.18

Source: Primary data

(₹ -7707.03), further this group was left with noticeable farm investment income of ₹ 5428.59, which was lowest among all the situations.

Thus, profitability of the cotton crop grown, varied across different farming situations. From the above results, it was clear that cultivation of cotton was economically viable in the irrigated and rainfed situations of black and red soils but was completely unviable under FS-3 (chalka soil).

Constraint analysis

Scores assigned by sample farmers for various constraints faced are confronted in the Table 5. Cotton growers under rainfed condition ranked lack of irrigation/ inadequate rainfall as the major

Table 5. Constraints faced by farmers under different farming situations

Constraints	FS-1		FS-2		FS-3		FS-4		FS-5		Pooled	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Production												
Small sized land holdings	52.47	3	51.57	3	52.14	2	48.11	3	58.46	3	52.55	2
Unsuitable soil condition	60.07	2	39.13	4	65.79	1	41.60	4	33.71	4	48.06	4
Crop failure due to unfavourable weather conditions	60.14	1	57.34	2	41.44	4	66.36	2	66.21	1	59.55	1
Inadequate rainfall/irrigation facilities/ excess rainfall	30.60	5	63.57	1	43.20	3	31.01	5	33.66	5	39.16	5
Infestation of insect pest and disease	52.29	4	37.89	5	30.00	5	63.14	1	61.60	2	48.98	3
Input												
Problem of labour availability	61.40	1	64.66	1	38.87	3	57.60	1	64.11	1	62.38	1
High cost of seeds, fertilizer and pesticides	35.89	3	46.74	2	47.01	2	46.20	3	52.71	2	49.08	2
Poor quality and low availability of inputs	52.71	2	38.60	3	64.11	1	52.26	2	38.60	3	40.84	3
Marketing												
Low price of output at the time of harvesting	62.57	1	60.89	1	55.97	2	53.74	2	63.36	1	60.71	1
Lack of infrastructure	59.64	2	51.39	3	63.00	1	57.86	1	42.21	5	46.43	5
Delay in payment by the marketing agencies	56.04	3	47.00	4	46.40	5	38.57	5	52.21	4	49.39	4
Lack of marketing knowledge	52.63	4	44.14	5	53.29	3	43.90	4	57.36	2	55.91	2
Poor marketing facilities	47.10	5	58.79	2	50.90	4	45.60	3	45.71	3	49.62	3
Institutional												
High rate of interest by the money lenders	50.50	1	50.44	3	52.89	5	44.47	5	49.51	3	47.53	5

Constraints	FS-1		FS-2		FS-3		FS-4		FS-5		Pooled	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Cumbersome procedure for taking loan	47.29	3	50.27	4	56.67	4	59.63	1	42.10	5	51.19	4
Lack of knowledge about bank loan processing system	49.06	2	60.73	1	60.43	2	52.51	3	56.00	2	55.75	1
Inaccessibility of financial institutions	45.76	4	55.59	2	61.09	1	49.81	4	47.06	4	51.86	3
Non-availability of timely credit	40.34	5	44.34	5	60.23	3	57.00	2	58.93	1	54.20	2
Technical												
Use of traditional technology	46.17	4	60.86	3	58.00	3	48.51	4	55.89	4	53.89	4
Inadequate agricultural research and extension	55.24	3	57.26	4	54.93	4	64.39	1	59.09	3	58.18	3
Inaccessibility to the concerned institutions (KVK, University)	59.90	2	60.86	2	62.06	1	62.39	2	66.00	1	62.24	1
Poor technical know how	59.79	1	62.36	1	59.49	2	61.71	3	62.36	2	61.14	2

Source: Primary data

production constraint while diseases and pest infestation was the major constraint among irrigated cotton growers (FS-1 and FS-4) (Kumar *et al.*, 2019). This was because, untimely irrigation with poor nutrient management, resulted in profuse plant growth with positively correlated pest population. Labour shortage during the peak season was extensively faced by the farmers resulting in hiked labour wages and thus raising the cost of cultivation. Cotton is a crop when exposed to wet conditions easily gets spoiled, hence farmers prefer to sell the crop immediately after harvest and this resulted in low price at the time of harvesting. This was mainly due to lack of proper storage facilities (Goud *et al.*, 2018). Poor or low technical knowledge had impact on the farmers in adoption of new technologies in FS-1 and FS-2 whereas, the cotton growers in black soils (FS-4 and FS-5) faced challenges in extension education and accessibility to concerned institutions.

CONCLUSION

The computation of costs and returns substantiated that cultivation of cotton was highly profitable under FS-4 followed by FS-1, FS-5 and FS-2. But, cultivation of cotton in the FS-3 left farmers with negative net returns affecting their future crop investment. Hence, cultivation of cotton crop under this situation was not economically viable. Thus, there is a need for shift in cotton cultivation to other suitable crops like ragi, bajra, jowar, ground nut and pulse crops.

The constraint analysis revealed that despite cultivating Bt-hybrids, cotton crop suffered from pest and disease attack. Hence, there is need for development of resistant traits and supply of good quality seeds. Adoption of high-density plantation system is to be promoted among farmers. Practicing mulching in rainfed areas can reduce the moisture stress and inhibit weed growth, thereby, reducing the labour cost. Application of recommended dose of fertilizers and plant protection chemicals with timely and adequate irrigation *via* water saving techniques in irrigated cotton would enhance the yields by reducing input costs. Following, crop rotation would improve soil fertility. Further, creation of better infrastructure facilities for better marketing and conducting training programmes to disseminate the new technologies is much needed.

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FARMERS' PERCEPTION ON AGRICULTURAL DEVELOPMENT IN TELANGANA STATE: SOME REFLECTIONS FROM VILLAGE SURVEY

B. VIJAY KUMAR[1], ALDAS JANAIAH[1], K. SUHASINI[1], SEEMA[2] and A. MEENA[3]

[1]Department of Agricultural Economics, College of Agriculture, Rajendranagar

[2]Dean of Agriculture, PJTSAU, Rajendranagar

[3]Department of Statistics and Mathematics, College of Agriculture, Rajendranagar

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ABSTRACT

Farmers in Telangana state expected big changes in agricultural sector after formation of separate state in 2014. Accordingly, government of Telangana initiated series of steps such as Rythu Bandhu, Rythu Bheema, free power for agriculture, etc. This paper made an attempt to assess the farmers perception with respect to change in various indicators of agricultural development after 2014. For this study two largely irrigated districts (progressive districts) and another two primarily rainfed districts (backward districts) were selected for conducting Focused Group Discussions (FGDs) in 40 villages (20 from irrigated districts and 20 from rainfed districts). Data from FGDs were analyzed using various statistical measures of central tendency to understand the changes in key indicators between 2014 and 2021. Results indicated that net area sown and gross area sown has increased by 9.57 and 34.76 per cent at state level between 2014 and 2021. Cropping intensity has also increased by 21 per cent between 2014 to 2021 in the state**,** implying that an additional 21 per cent of net area was sown more than once in a year primarily due to stabilization of irrigated area under village tanks. Similar findings were also reported during the FGDs in the sample villages. It is also reported that number of agricultural labors declined between two periods primarily due to growing mechanization and also non-farm employment opportunities. Farmers also expressed that the cost of key farm inputs such as fertilizer, farm machinery and labor has been significantly increased by about 60 to 120 per cent, while the increase in output prices was around 70 per cent between 2014 and 2021. The farm level yields were merely stagnant between 2014 and 2021. These farm level trends indicated that there are no major changes in real profitability of major crops.

Key words: Agricultural sector, Rural households, Agricultural development

Telangana as a part of erstwhile Andhra Pradesh was known for its backwardness in all respects- social, economic and cultural development. One of the reasons for its backwardness was negligence of the region during the regime of erstwhile Andhra Pradesh. In particular two perceptions have been dominated the conventional wisdom. First, it is argued that agriculture in Telangana has long been both backward and stagnant. Second, it is argued that Telangana suffers from a serious insufficiency of irrigation resources (Simhadri and Rao, 1997). There was growing disparity of people living in urban centers and rural areas which was reflected in increased farm distress and large number of suicides by farmers (Reddy and Bantilan, 2013; Reddy *et al.* 2014). Therefore, farmers distress has become a serious issue prior to the formation of separate state.

In view of the above, the separate Telangana movement largely led by peasants since mid-1960's has gained considerable momentum and finally Telangana state was created by bifurcation of the erstwhile Andhra Pradesh in June 2014. It was expected that most of the agrarian related problems would be solved in separate state of Telangana. Accordingly, the Telangana state government has given top priority to agriculture, irrigation and farmers welfare by initiating several innovative policies as well as major irrigation projects. Notable policies and initiatives are special focus on irrigation projects and rehabilitation of village tanks (Mission Kakatiya), continuation of free power for 24 hours to the farmers, debt waiver up to one lakh rupees, direct investment support scheme (*Rythu Bandhu Scheme*) with provision of Rs. 5000 per acre per season without any ceiling on land holding, continuation of interest free loans, assured marketing and expansion of storage structures for farm produce etc.

All these new initiatives and policies are expected to enhance agricultural production thereby income of the farmers in order to minimize the farmers distress in the state. In this regard, an attempt was made to document the farmers perception with respect

Email: vijaykumar.b24@gmail.com

to various indicators related to agricultural development after 2014 and to assess the reflections of farmers perceptions regarding micro level changes with macro level indicators.

MATERIAL AND METHODS

The newly formed Telangana state was purposively selected for the present study. Based on irrigated area, two largely irrigated districts (Karimnagar and Nalgonda) and another two primarily rainfed districts (Adilabad and Ranga Reddy) were selected for the study. By consulting the district officials, two well developed mandals from each progressive district and two less developed mandals from each backward district were selected. Same criteria have been followed for selection of the villages. To understand the farmers perception towards transformation of agriculture after formation of separate Telangana state, a Focused Group Discussion (FGDs) with key informants consisting 8-10 knowledgeable and experienced farmers in each village was conducted. A total of 40 villages were selected at the rate of 10 villages from each district (20 well developed and 20 less developed) and the same were analyzed using tabular analysis and arithmetic measures.

RESULTS AND DISCUSSION

A. Changes in the macro indicators of agricultural development

The special focus given to the agricultural sector after formation of separate Telangana state such as Rythu Bandhu, Rythu Bheema, loan waiver and free power to agriculture were expected to enhance agricultural growth and farmer income in the state. Changes in the selected key macro level indicators related to agriculture between 2014 and 2021 were summarized and presented in the Table 1. Net and gross sown area has shown an increase of 9.57 and 34.76 per cent respectively between 2014 and 2021. Cropping intensity has also increased by 21 per cent between 2014 to 2021, implying that an additional 21 per cent of net area was sown more than once in a year primarily due to stabilization of irrigated area under village tanks. Paddy and cotton area were also substantially increased. Paddy and cotton yield has also shown positive trends. According to the data available, irrigated area has shown negative growth between 2014 and 2020. However, according to the data available pertaining to the 2021 (Socio-Economic Outlook, 2022) the gross irrigated area was 55.23 lakh hectares but there was no mention about net irrigated area. Looking at the above trends it is clearly evident that after formation of separate Telangana, the state has achieved considerable progress in agricultural sector.

B. Some reflections of farmers on agricultural development

To validate these state level trends with respect to farmers perception, 40 FGDs in 40 villages in different parts of the state were conducted and the results were presented as follows.

Table 1. Changes in the cropped area and irrigated area in Telangana, 2014 and 2021

S. No.	Indicator	June, 2014	June, 2021	Difference (2014-2021)
1.	Net area sown (lakh ha)	49.61	54.36	4.75 (9.57%)
2.	Gross area sown (lakh ha)	62.88	84.74	21.86 (34.76 %)
3.	Cropping intensity (%)	127.70	154.52	26.82 (21 %)
4.	Net irrigated area (lakh ha)	22.89	22.03*	-0.86 (-3.75 %)
5.	Gross irrigated area (lakh ha)	31.64	31.22*	-0.42 (-1.32 %)
6.	Paddy area (lakh ha)	20.02	42.83	22.81 (113.93 %)
7.	Paddy yield (Kg/ac)	4549	5494	945 (20.77 %)
8.	Cotton area (lakh ha)	17.07	24.43	7.36 (43.11 %)
9.	Cotton yield (Kg/ac)	502	522	20 (3.98 %)

NOTE: June 2014 and June 2021 are referred to Agri Years 2013-14 and 2020-21 respectively.
Source: Telangana Socio Economic Outlook 2015 and 2021, Govt of Telangana.
*Data related to June 2020, Source: Agricultural action plan 2020-21, Government of Telangana.
Figures in parenthesis indicates per cent difference between two periods.

I. Socio-economic profile of sample villages

The socio-economic profile of the sample villages has been presented from Table 2 to 5. As can be observed the female population growth was higher (10.11 %) compared to male population (9.20 %) from 2014 to 2021. Total households have increased by 12 per cent between 2014 to 2021. Similarly, average number of farm households per village in the state have also increased by 10 per cent between 2014 to 2021 (Table 2). Whereas, number of agricultural laborer's have declined between two periods. Increased farm mechanization and non-farm employment opportunities in the recent years could be the reasons for the decreased agricultural labor in the selected villages as non-agricultural sector has been emerging as a source of employment in the rural areas (Radhakrishna, 2020). This shift has taken place among the economically weaker sections (Saha and Verick, 2016).

Proportion of small farmers to the total number of farmers have increased about 8 per cent (Table 3). The reason behind increase in per cent of small farmers could be fragmentation of land to their successive generations. Similar findings were reported by Macharla and Lal (2017) in their study. All other categories exhibited declining trend from 2014 to 2021. Among all other categories percent of large farmers registered higher negative growth of 20 per cent.

It is interesting to note that the various assets such as smart phones, farm machinery, etc. owned by the rural households in the state have almost doubled between 2014 to 2021 (Table 4). On contrary livestock population has significantly decreased in the state during the recent past (Table 5). The decline is more prominent cattle and milch-cows population. Whereas, goat's/sheep's population has seen minimal decline (-27.17 %) due to Telangana Sheep Distribution scheme which is a subsidized sheep distribution scheme by the Government of Telangana. Deficit veterinary infrastructure and negative growth rate in livestock population in Telangana could be the reason for the same. These results were also in line with the sectoral paper on animal husbandry, NABARD (2018).

II. Changes in the cropped, irrigated area, cropping pattern in the sample villages

Particulars of the changes in the cropped area and irrigated area, cropping intensity and farm input costs in the selected villages of Telangana were presented in Table 6 and 7. Net sown area and gross sown area have increased by 11.24 and 16.55 per cent respectively between 2014 to 2021 and the same has been reflected at macro level in the state. Net area sown and gross area sown has increased by 9.57 and 34.76 per cent at state level between 2014 and 2021. Net irrigated area as per cent of net sown area has also shown considerable increase (Table 6). According to the farmers, the cropping intensity has increased around 5 per cent which is less than the states increase which was 21 per cent between 2014

Table 2. Changes in the demographic and occupational features in the selected villages of Telangana, 2014 and 2021

(Average/village)

S. No	Indicator	2014	2021	Difference
1	Population (number)	1708	1873	165 (9.66%)
	a. Male	858	937	79 (9.20%)
	b. Female	850	936	86 (10.11%)
2	Total households (number)	442	499	57 (12.89%)
	a. Per cent of female headed households	3.13	4.46	1.33 (42.49%)
3	Total number of farm households	393	436	43 (10.94%)
4	Number of cultivators including tenants	411	456	45 (10.95%)
5	Number of tenants	21	28	7 (33.33%)
6	Number of agricultural labours	102	96	-6 (-5.88%)

Source: Field survey data, 2021
Figures in parenthesis indicates per cent difference between two periods

Table 3. Distribution of farmers by land holding in the selected villages of Telangana, 2014 and 2021

(Average/village)

S. No	Indicator	2014	2021	Difference
1	Total farmers (number)	393	436	
	a. Per cent of marginal farmers	44	43	-1 (-2.27%)
	b. Per cent of small farmers	36	39	3 (8.33%)
	c. Per cent of medium farmers	15	14	-1 (-6.66%)
	d. Per cent of large farmers	5	4	-1 (-20%)

Source: Field survey data, 2021
Figures in parenthesis indicates per cent difference between two periods

Table 4. Changes in the assets owned by the farmers in the selected villages of Telangana, 2014 and 2021

(Average/village)

S. No	Indicator	2014	2021	Difference
1	Two wheelers (% of total households)	38	96	58 (152.63%)
2	Smart phones (% of total households)	30	77	47 (156.66 %)
3	Number of tractors	10	24	14 (140%)
4	Number of combined harvesters	1	2	1 (100%)

Source: Field survey data, 2021
Figures in parenthesis indicates per cent difference between two periods

Table 5. Changes in the livestock population in the selected villages of Telangana, 2014 and 2021

(In numbers)

S. No	Livestock	2014	2021	Difference
1	Cattle	356	91	-265 (-74.43%)
2	Milch-cows	237	104	-133 (-56.11%)
3	Milch buffaloes	277	155	-122 (-44.04%)
4	Goats/sheep’s	736	536	-200 (-27.17%)

Source: Field survey data, 2021
Figures in parenthesis indicates per cent difference between two periods

Table 6. Changes in the cropped area and irrigated area in the selected villages of Telangana, 2014 and 2021

(Average/village)

S. No	Farmers perception on	2014	2021	Difference
1	Net sown area (acres)	1192	1326	134 (11.24%)
2	Gross sown area (acres)	1740	2028	288 (16.55%)
3	Cropping intensity (%)	146	153	7 (4.79%)
4	Net irrigated area as per cent of net sown area	44.67	56.04	11.37 (25.45%)

Source: Field survey data, 2021
Figures in parenthesis indicates per cent difference between two periods

Table 7. Changes in the cropping pattern in the selected villages of Telangana, 2014 and 2021

(Average/village)

S. No	Indicator	2014	2021	Difference
1	Gross cropped area (acres)	1740	2028	288 (16.55%)
	a. Per cent area under paddy	40.47	48.79	8.32 (20.55 %)
	b. Per cent area under maize	6.14	5.00	-1.14 (-18.56%)
	c. Per cent area under cotton	41.77	36.37	-5.4 (-12.92%)

Source: Field survey data, 2021
Figures in parenthesis indicates per cent difference between two periods

to 2021.

Although the state has witnessed an increase in area of major crops like paddy and cotton, the same were almost stagnant according to farmers in the selected villages of the state. Among the three crops (paddy, maize and cotton) only percent area under paddy crops has increased at 20.55 per cent (Table 7). Whereas, area under maize and cotton has declined by 18.56 and 12.92 per cent respectively from 2014 to 2021.

I. Changes in the farm input cost, yield and market prices of major crops in the sample villages

According to the data expressed by FGDs with farmers, farm input cost of major crops between 2014 to 2021 has increased. Increase in fertilizer cost 28-28-0 and DAP was 118.18 and 84.28 per cent respectively. Whereas, it was 50.50 per cent in case of urea. Machinery hiring charges were also hiked up by 61.82 per cent between 2014 and 2021. These results were also in conformity with the findings of Srivastava *et al.* (2017) conducted in India. Female and male labor wages were almost doubled in from 2014 to 2021 in the state (Table 8). Labor has become scarce in rural Telangana due to factors like growing migration to urban centers, MGNREGA, increasing opportunities in construction works as contract laborer within and outside villages resulted in significant increase in wage rates. Similar findings were also witnessed by Reddy (2020) in his study conducted in Telangana.

Except maize, paddy and cotton have exhibited decline in their yields. Though the increase in maize yield was 8 per cent as compared to the yield

Table 8. Changes in the farm input costs of major crops in Telangana, 2014 and 2021

(Average/village)

S. No	Input	2014	2021	Difference
1	Fertilizers (Rs/bag)			
	a. Urea	200	301	101 (50.50%)
	b. DAP	738	1360	622 (84.28%)
	c. 28-28-0	594	1296	702 (118.18%)
2	Machinery hiring charges (Rs/ac)	1378	2230	852 (61.82%)
3	Labour wages (Rs/day)			
	a. Male	317	615	298 (94.00%)
	b. Female	158	335	177 (112.02%)

Source: Field survey data, 2021
Figures in parenthesis indicates per cent difference between two periods

Table 9. Changes in the yield, and market prices of major crops in the selected villages of Telangana, 2014 and 2021

(Average/village)

S. No	Indicator	2014	2021	Difference
1	Yield (q/ac)			
	a. Paddy	24	23	-1 (-4.16%)
	b. Maize	25	27	2 (8.00%)
	c. Cotton	7	5	-2 (-28.57%)
2	Farm output prices (Rs/q)			
	a. Paddy	1192	1817	625 (52.43%)
	b. Maize	1011	1761	750 (74.18%)
	c. Cotton	4648	8896	4248 (91.39%)

Source: Field survey data, 2021
Figures in parenthesis indicates per cent difference between two periods

of 2014. Farm out prices of cotton found to be increased maximum compared to other two crops which was 91.39 per cent (Table 9). Whereas, paddy and cotton have shown increase in their yield at macro level. With regards to Minimum Support Price (MSP) compared to farm output prices in the selected villages of Telangana, only cotton crop farm output price (Rs. 4648 in 2014 and Rs. 8896 in 2021) was more than MSP in 2014 (Rs. 3700/q) as well as in 2021 (Rs. 5515/q). Whereas, paddy and maize crops MSP was higher than the farm output price in 2014 and 2021.

CONCLUSION

The results of the study indicated that there has been a considerable increase in number total farm households, as well as farm house holds by more than 10 per cent between 2014 and 2021 in the selected villages. There is a decline in large and increase in small farm holdings due to fragmentation of agricultural land from parents to their descendants. Hence, the government policies should be framed according to small farmers welfare. Whereas, percentage of gross sown area and net sown area has increased both at micro and macro level in the state. Though the increase in net sown area have shown nearly same results both at micro and macro level, increase in gross sown area was more at macro level compared to micro level. The rural assets of households in the sample villages such as mobile phones, two-wheeler vehicle, tractor, etc. were nearly doubled between 2014 and 2021 which is considered as an indicator of positive change in rural sector with the formation of Telangana as a separate state. Wages for both male and female were also almost doubled from 2014 to 2021. Except maize, paddy and cotton has exhibited decline in their yields. Whereas, paddy and cotton has shown increase in their yield at macro level. Finally, low farm output prices in case of paddy and maize is one of the major problems being faced by the farmers of sample village. And the study suggested that more emphasis should be given on delivering MSP benefits and making government schemes available to the farmers on time in order to boost agricultural development in the state.

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Research Article
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GROWTH OF SEED INDUSTRY IN INDIA *VIS-À-VIS* TELANGANA

S. KAVI RAJU[1], A. JANAIAH[1], R. VIJAYA KUMARI[2], P. RADHIKA[3] and D. SRINIVASA CHARY[4]
[1]Department of Agricultural Economics, College of Agriculture, Rajendranagar
[2]Deputy Director of Research, PJTSAU, Rajendranagar
[3]School of Agri Business Management, Rajendranagar
[4]Department of Statistics and Mathematics, College of Agriculture, Rajendranagar

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ABSTRACT

This paper examines the trends in growth of seed industry in India and Telangana with special focus on rice seed sector. The compound annual growth rate (CAGR) method was used to estimate the growth in distribution of certified seeds of important crops with special focus on certified seed of rice. While, the size of seed business computed for two different points of time 2014 and 2020 to understand the relative importance of Telangana in Indian seed industry. The size of global seed business increased by about 15 per cent between 2012 and 2020. Subsequently, the India's share in global seed business has increased from about 4 to 6 per cent during the same period. On other hand, the relative share of Telangana in the Indian seed business has declined from about 30 to 19 per cent between 2014 and 2020 respectively. The reason for this change is a sizeable portion of seed industry being shifted to other neighbouring states specially in case of hybrid rice and Bt cotton seed production. The distribution of certified seed of all crops in India and the state of Telangana has shown a positive compound annual growth rate over the past 20 years, with deceleration in growth rates in recent period. The relative shares of seed production area under hybrid rice and BT cotton hybrids to total area under seed production in Telangana declined from about 23.3 to 13.3 per cent and 8 to 4.75 per cent respectively between 2014 and 2020. However, total area under seed production for all crops and seed growers increased substantially in the state between this period. Hence, the seed growers in Telangana state may be provided with the required incentives along with formulation of a comprehensive seed production policy for further promotion of seed industry.

Key words: seed industry, seed business, growth, certified seed, rice seed sector, India, Telangana.

The use of quality seed for every crop season improves the yield by 12 to 17 per cent in India (Pal *et al*., 2000). Given the rising demand for food grains and the limited availability of land resources, adopting high-quality seeds can also increase yield by about 15 to 20 per cent (Chauhan *et al.,* 2000). Similarly, it was reported that the use of cleaned farm saved seed can increase paddy yield by 8 to 10 per cent in Bangladesh (Diaz *et al.,* 2000). In Vietnam 60 per cent of rice farmers change their seeds for each season (Khoa *et al.,* 1996). Further, it was observed that the average paddy yield was high in the states where seed replacement rates also high in India (Janaiah, 2003).

Keeping in view the role of seed in agriculture, the development of a seed provisioning system is always an integral part of the agricultural development strategy since 1960s in India. As a result, the domestic seed industry in the country was initially promoted by the public sector, a major player, while private sector participation was restricted till the early 1980s. Subsequently, the private seed firms started participation in seed sector specially on the distribution of high value hybrids in maize, cotton, pearl millet, sorghum, and hybrid vegetables, where incentives are greater (Pandey *et al.,* 2017). However, it was observed that the significant participation of private sector firms in the production and sale of public varieties was noticed in Andhra Pradesh in the case of rice seed. In addition, the other reason for the entry of private sector firms into the inbred rice seed market is that they wanted to promote hybrid rice varieties along with the inbred rice seed varieties in the early 1990s (Pal and Trip, 2002).

Telangana state, previously a part of erstwhile Andhra Pradesh, is widely considered as seed hub of India. The favourable climatic conditions, farmers experience in seed production, geographical advantage and favourable state policies were the key factors for becoming Telangana region as a seed hub in the regime of erstwhile Andhra Pradesh. It was reported that nearly one third of India's seed of inbred rice varieties was produced in erstwhile Andhra Pradesh during late 1990s. (Pal *et al*., 2000). Further nearly 80 per cent of area under hybrid rice seed production was concentrated in Telangana State (Janaiah and Xie,

Email: kavi10warangal@gmail.com

2010). Soon after formation of Telangana as separate state in 2014, the state government has further committed to strengthen and promote the seed industry in the state in view of its huge employment potential.

With this background, this paper critically analyses the trends in growth of seed industry with special focus on rice seed sector after farming the Telangana as separate state in 2014.

MATERIAL AND METHODS

The secondary data regarding distribution of certified seeds and monetary value of India's domestic seed market and its growth have been compiled from various reports of Directorate of Economics & Statistics, Ministry of Agriculture, Government of India, NABARD (National Bank for Agricultural and Rural Development), TSSOCA (Telangana State Seed & Organic Certification Agency), TSSDC (Telangana State Seed Development Corporation), State Department of Agriculture and R & D institutes. Further, seed industry experts were also consulted to collect data on the performance of seed industry in the state of Telangana. Apart from this, the compound annual growth rates (CAGR) were calculated for distribution of certified seeds of important crops with a special focus on the rice seed in both India and Telangana from 2001 to 2020 and 2003 and 2020 respectively. However, the size of seed business computed for two different point of times 2014 and 2020 to understand the relative importance of Telangana in Indian seed industry. A simple tabular and arithmetic measures were used to analyze the data to arrive at meaningful conclusions.

RESULTS AND DISCUSSION

A. Trends in seed business: India vis-à-vis Telangana

The estimated size of the global seed business increased by about US$7 billion and reached US$52 billion in 2020, up from US$45.2 billion in 2012. The USA has occupied first place, accounting for US$13 billion in the global seed market. However, the relative share of the USA and China in the global seed business declined between 2012 and 2020, while the shares of France, Japan, and India increased substantially (Table 1). In 2012, India stood at sixth place in the global seed market and now it is the fifth largest seed market in the world after the U.S. (24.8%), China (21%), France (6.7%), and Brazil (6.1%). Similarly, the share of India's seed business in the global seed market has increased from about 4.4 to 6 per cent between 2012 and 2020. Likewise, the size of Indian seed market has increased from US$ 2 to US$ 3.1 (Table 1).

Table 1. Share of major countries in global seed business between 2012 and 2020

S. No	Country	Market size in 2012	Global share (%) (in $ billion)	Market size in 2020 (in $ billion)	Global share (%)
1	USA	12	26.5	13	24.8
2	China	10	22.1	11	21.0
3	France	2.8	6.2	3.5	6.7
4	Brazil	2.6	5.8	3.2	6.1
5	Canada	2.1	4.6	2.8	5.3
6	India	2	4.4	3.1	5.9
7	Japan	1.4	3.1	1.7	3.2
8	Germany	1.2	2.7	1.4	2.7
9	Argentina	1	2.2	1.1	2.1
10	Italy	0.8	1.8	1	1.9
11	Others	9.3	20.6	10.55	20.3
	Total	45.2	100	52.4	100

Source: www.oecd-ilibrary.com, www.worldseed.org

The Indian seed market has witnessed major changes in its growth structure in recent years, primarily due to the large-scale participation of the private sector after liberalising the seed policy in the late 1980s, enabling the import of the best seeds and planting materials and to making them available to farmers. Further, technological innovations like PPV & FR (Protection of Plant Varieties and Farmers' Rights act) and the introduction of Bt cotton have built confidence in the private sector both in terms of intellectual property rights (IPR) and higher investment in research and development (Paroda, 2013). As a result, seed business in India has almost doubled during the past decade due to an increase in seed replacement rates (use of quality seeds) for open pollinated crops, wide usage of hybrid varieties for field crops along with vegetables (Kumar *et al.* 2018). It was reported that 3 per cent increase in seed replacement rate between 1998-99 and 1990-91 contributed to a significant increase in market size in terms of both quantity and value with aggressive private sector participation in India (Gadwal, 2003). For instance, the average seed replacement rate of rice has increased from about 40 per cent in 2011 to 64 per cent in 2017 in India. This increase in seed replacement rate resulted in an increase in the average seed yield of paddy in India (Figure 1). As a result, demand for quality seeds has been increasing.

In addition to this, the market for Bt cotton hybrids increased both in terms of value and volume from about ₹ 3200 to ₹ 3700 and 400 to 500 lakh packets (450 gram each) also a major contributor to growth of seed business in India between 2011 and 2020 (Manjunatha *et al.,* 2012 and NSAI report on seed industry submitted to NABARD, 2020). The other key elements for this growth are the commercialization of the agriculture sector, growing number of public-private collaborations, and the development of hybrid product variants.

As indicated above in Figure 2, the estimated value of the seed business in India is about ₹ 22,500 crores ($3.1 billion), in which the varietal and hybrid seed industry shares are 55 and 45 per cent respectively.

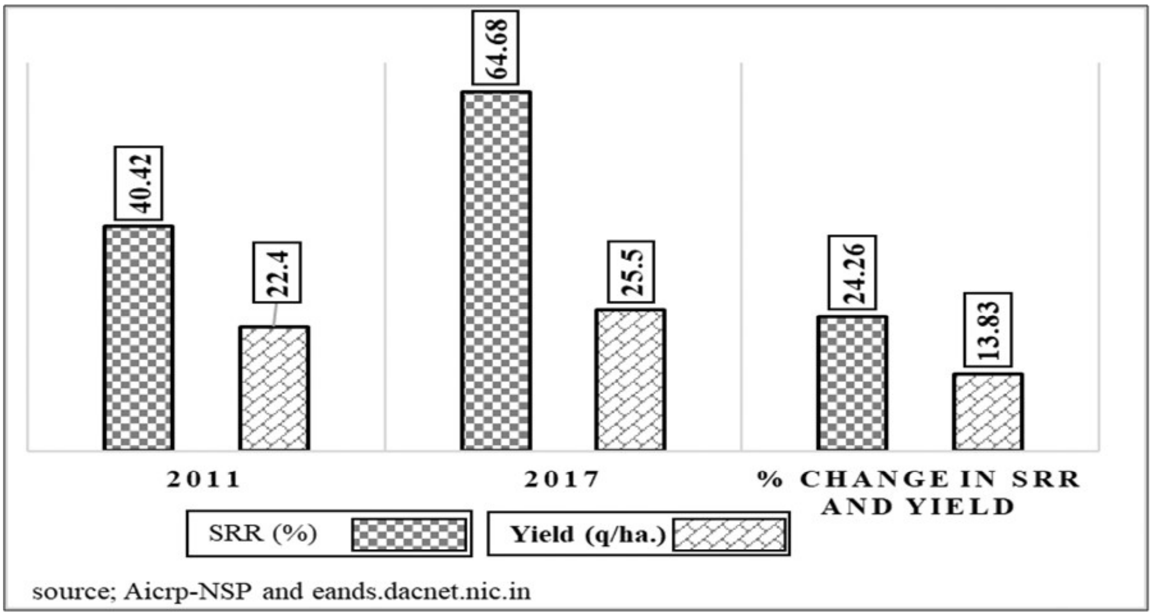

Figure 1. Seed replacement rate and yield of paddy in India in 2011 and 2017

Among the hybrid crops, Bt cotton accounts for 37 per cent of hybrid seed industry, followed by vegetable seed (26%), maize (18%), and hybrid rice seed (12%). On contrary, millets and oilseeds account for a very negligible share in the hybrid seed market due to the less cultivated area under these crops compared to the crops specified above (Figure 3). In addition to this, the majority of farmers in the country still depend on non-hybrid farm saved seeds in the case of oil seeds, cereals and pulses. Though the area under vegetable crops is less compared to oilseeds and millets, their share in the hybrid seed market is

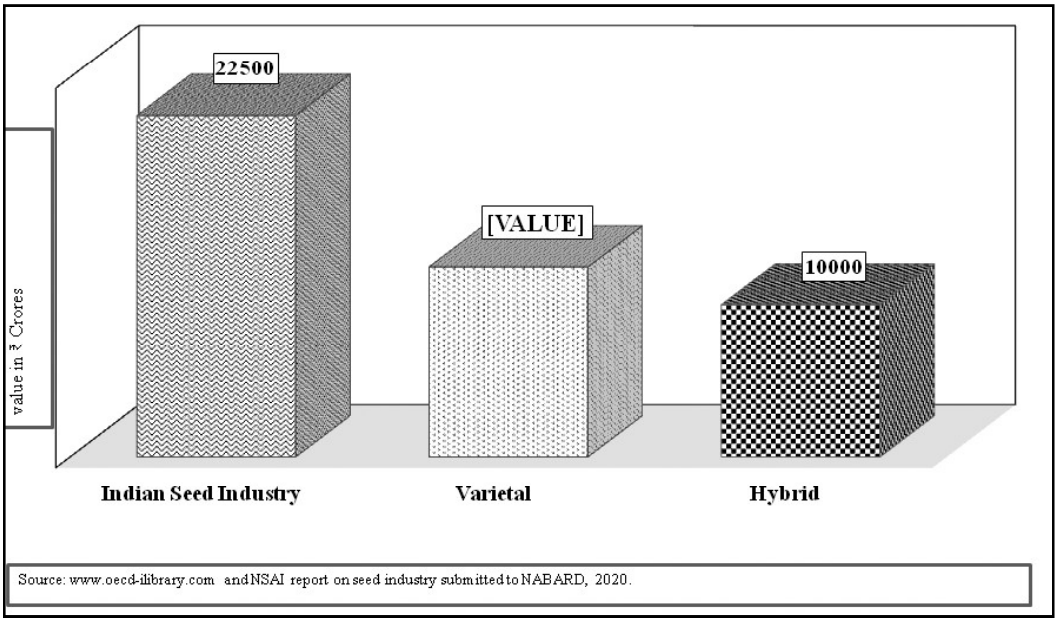

Figure 2. The size of Indian seed business in 2020

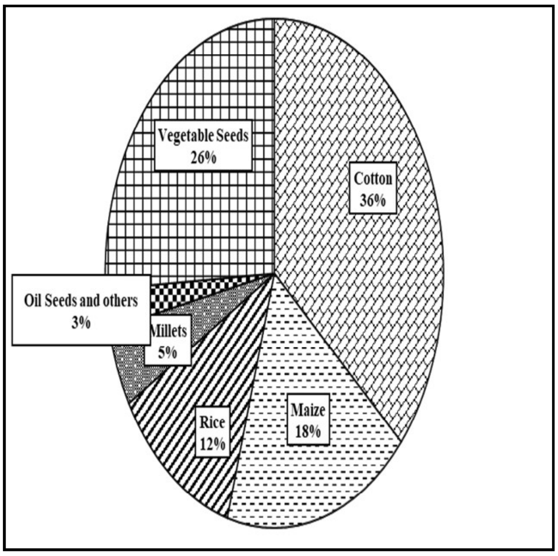

Figure 3. Share of various crops in hybrid seed business of India (%)

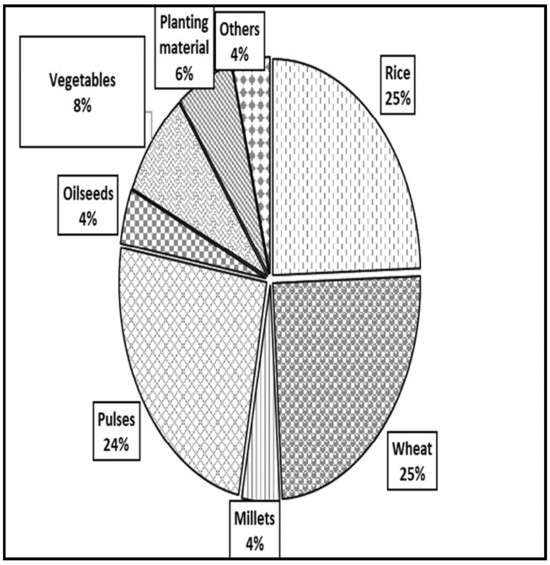

Figure 4. Share of various crops in inbred seed business of India (%)

very substantial due to the high value for their hybrid seeds. Similarly, the share of rice (25%) and wheat (25%) alone accounted for 50 per cent in the inbred seed market, followed by pulses (24%) and vegetables (8%) (Figure 4).

B. Seed industry in Telangana

Telangana state is conventionally considered as seed hub of India, with the presence of about 400 seed companies including major multi-national companies with considerable logistics such as strong processing capacity (850 tonnes/hour), storage facilities, presence of various public and private research organisations, skilled labour and seed farmers engaged in seed production for different seed agencies. Out of India's total paddy seed requirement, 70 per cent of hybrid and 30 per cent of inbred paddy seed is being supplied by Telangana alone (NSAI report on seed industry submitted to NABARD, 2020).

However, in recent years, a sizeable portion of seed industry has been shifted to other neighbouring

Table 2. Growth of seed industry in Telangana state between 2014 and 2020

S. No	Indicators	2014	2020	Difference(%)
1	Total area under seed production of all crops (acres)	472400	599400	26.88
2	Number of registered seed companies	400	450	12.50
3	Total number of seed growers	300000	320000	6.67
4	Area under hybrid rice seed production (acres)	110000 (23.3)	80000 (13.3)	-27.27
6	Quantity of hybrid rice seed produced(tonnes)	51750	41160	-20.46
7	Number hybrid rice seed growers	66865	51428	-23.09
8	Area under inbred rice seed production (acres)	190000 (40.2)	350000 (58.4)	84.21
9	Quantity of inbred rice seed produced (tonnes)	386000	700000	81.35
10	Number inbred rice seed growers	86300	159000	84.24
11	Area under cotton seed production (acres)	38000 (8.0)	28500 (4.7)	-25.00
12	Quantity of cotton seed produced (tonnes)	10450	7500	-28.23
13	Number of cotton seed growers	58000	40600	-30.00
14	Area under hybrid maize seed production (acres)	18000	13000	-27.8

Source: Extracted and compiled from various reports and personal consultation with seedmen Association, Hyderabad.
Note: Seed data includes certified seed from TSS&OCA and truthful labelled seed of various agencies.
Note: figures in parentheses indicates per cent to the total area under seed production of all crops.

states specially to Chhattisgarh in case hybrid rice seed due to special incentive Rs. 500/quintal being given to seed growers registered with seed corporation of Chhattisgarh (Report on centrally and state sponsored schemes, Government of Chhattisgarh, 2019). Similarly, cotton seed production area being shifted to Karnataka due to less cost of production and more climate suitability compared to Telangana state. Likewise, hybrid maize seed production is being shifted to Andhra Pradesh. Correspondingly, area under hybrid rice seed production and cotton seed production has declined by about 27 and 25 per cent between 2014 and 2020 respectively (Table 2). As a result, the relative shares of seed production area of hybrid rice and BT cotton hybrids to total area under seed production declined from about 23 to 13 per cent and 8 to 4.7 per cent respectively during this period (2014 and 2020). In a consequence, the share of Telangana in India's seed business has declined from about 30 to 19 per cent between 2014 and 2020 (Figure 5).

On the contrary, number of seed companies and number of seed growers specially for inbred rice seed production (non-hybrid) have increased between 2014 and 2020. Accordingly, the relative share of area under inbred rice seed production has increased from about 40 per cent to 58 per cent between 2014 and 2020 (Table 2). It may be noted that most of emerging seed companies and seed growers were small in size as small dealers with meagre logistic facilities. These newly entered companies and growers have primarily focused on seed production of popular paddy varieties, largely publicly bred paddy varieties to grab the increasing demand for purchased seed. The key factor for this rise in demand is due to the cultivated area under rice increased from about 34.97 lakh acres in 2014-15 to 104 lakh acres 2020-21 (Telangana Socio Economic Outlook, 2022). In addition to this, the government's special effort to promote seed replacement is another factor for increased demand for rice seed in recent years.

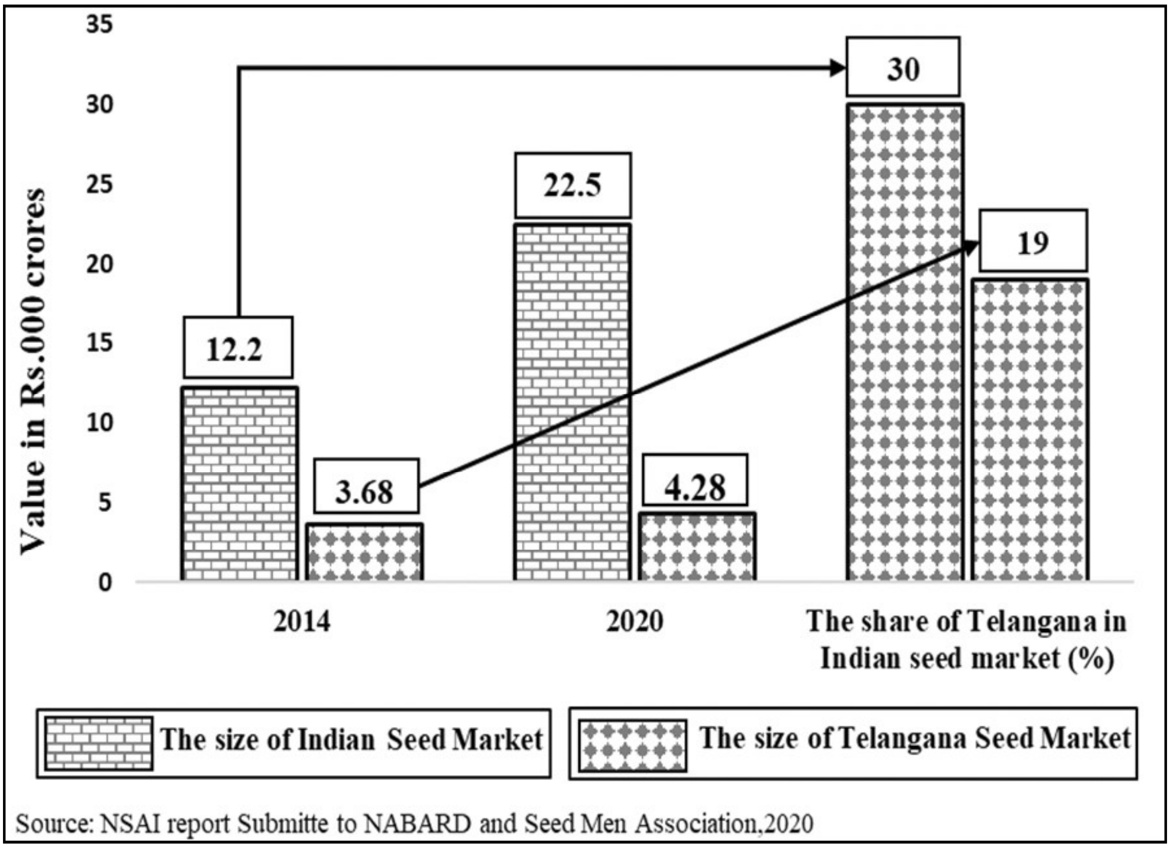

Figure 5. The Size of Indian and Telangana Seed Market

C. Trends in distribution of certified seed

i) Growth in certified seed distribution of various crops in India

Compound annual growth rates for the distribution of certified seed of various crops have been calculated for two points of time i.e., 2000-01 to 2009-10 and 2009-10 to 2091-20 and presented in Table 3. A progressive growth was found in the distribution of certified seed in all crops between 2000-01 and 2009-10 due to rapid increase in seed replacement rates (SRR) at annual growth ranging from 10 to 17 per cent witnessed in the case of rice across various states in the country. In addition, the SRR of Wheat, Bengal gram, green gram and groundnut increased at a CAGR of 13, 19, 6 and 15 per cent per year respectively during this period (Manjunatha *et al.* 2012). However, very minute development in the growth of certified seed distribution was observed in all crops except oil seeds between 2009-10 and 2019-20 as maximum increase in SRR was attained in the last decade (2000-01 to 2009-10) (Table 3). On the contrary, there was negative growth witnessed in the case of oil seeds during the same period (Table 3). This was mainly due to the substantial increase in the use of proprietary hybrids in the case of sunflower, which was highly dependent on publicly bred varieties a decade ago (2000-01 to 2009-10). As a result, the distribution of publicly bred varieties of sunflower fell dramatically, owing to the negative (-0.67 %) growth rate in the distribution of certified oil seeds (Table 3).

ii) Requirement and availability of certified seed of rice in India

The compound annual growth rates for the requirement and availability of certified seed of rice by various public and private sector seed agencies are computed for the period 2012– 13 to 2021–22 and presented in Table 4.

The requirement and availability of certified seed of rice have been increasing over the period from 2012–13 to 2021–22. However, the growth rate in total availability is more than the total requirement during this period due to the great increase in the participation of private firms in certified rice seed distribution due to huge demand for quality seed in the market. However,

Table 3. Compound annual growth rate of certified seed distribution of various crops in India from 2000- 01 to 2019-20

S. No	Crops	2000-01 to 2009-10	2009-10 to 2019-20	2000-01 to 2019-20
1	Rice	11.34 ***	2.52 **	7.25 ***
2	Wheat	12.89 ***	3.12 **	8.62 ***
3	Pulses	15.93 ***	4.34 ***	10.91 ***
4	Oilseeds	16.17 ***	-0.67	8.09 ***

Source: Directorate of Economics & Statistics, Ministry of Agriculture, GOI.
Note: *** significant at 1 per cent level, ** significant at 5 per cent level.

Table 4. Requirement and availability of certified rice seed by public and private sectors in India from 2012-13 to 2021-22. (Qty. in lakh quintals) **(Per cent/year)**

S. No	Year	Requirement	Availability	Availability by	
				Public sector	Private sector
1	2012-13	78.0	80.32	44.63(55.57)	35.69(44.43)
2	2013-14	82.4	89.95	47.99(53.35)	41.97(46.66)
3	2014-15	84.8	92.92	46.46(50.00)	46.46(50.00)
4	2015-16	82.9	95.10	47.96(50.43)	47.14(49.57)
5	2016-17	87.7	100.47	63.14(62.84)	37.33(37.16)
6	2017-18	89.5	104.07	52.47(50.42)	51.60(49.58)
7	2018-19	82.6	95.77	47.87(49.98)	47.89(50.02)
8	2019-20	82.4	92.28	52.21(55.90)	40.70(44.10)
9	2020-21	98.8	108.8	51.5(47.33)	57.3(52.67)
10	2021-22	103.3	120.2	-	-
11	CAGR	0.96 **	1.31 **	0.89	0.85

Source: Agriculture statistics at a glance (various issues), Directorate of Economics & Statistics, Ministry of Agriculture, GOI.
Note: *** significant at 1 per cent level, ** significant at 5 per cent level.

the public sector's share of seed production in the country declined from approximately 42 to 35 per cent in between 2017-18 and 2020-21, while the private sector's share increased from approximately 57 to 64 per cent during the same period (The Hindu, July 2nd, 2021). Similarly, it was noticed that the per cent share of the public sector in the distribution of certified seed of rice declined from about 63 to 47 per cent in recent past (2016-17 to 2020-21), while the share of the private sector is gradually increasing from 2012-13 to 2020-21 (Table 4). The prime contributor to this is that the farmers showing an interest in purchasing seed not only because of genetic purity but also because the seed companies deliver the clean and pure seed at the desired time, which is difficult in the case of farm saved seed. Besides this, the seed cost in rice production is very less compared to other inputs.

iii) Certified seed distribution in Telangana

The compound annual growth rates for the quantity of rice seed certified, registered rice seed growers, and registered area under rice seed production in Telangana are calculated and the same indicators have been compared with total quantity of seed certified, registered seed growers and area registered for all crops in the state over an eighteen-years period from

Table 5. Growth in certified seed, registered area and registered seed growers of paddy and other crops in Telangana from 2002-03 to 2019-20

(Per cent/year)

S. No	Indicators	2002-03 to 2010-11	2010-11 to 2019-20	2002-03 to 2019-20
1	Quantity of total certified seed of all crop	8.31 ***	-0.86	3.28 ***
2	Quantity of rice certified seed	6.52 ***	0.12	3.17 ***
3	Area registered under total seed production	8.83 ***	-1.18	3.23 ***
4	Area registered under paddy seed production	5.44 ***	-0.07	2.28 ***
5	Registered seed growers of all crops	6.35 ***	0.26	1.65 **
6	Registered paddy seed growers	4.76 **	-0.27	1.12 *

Source: Authors own estimates using data from various annual reports of TSSOCA.
Note: ***significant at 1 per cent level, ** significant at 5 per cent level.
Note: The details related to quantity of seed certified, seed grower and area registered by TSSOCA only and seed distributed. through private sector as truthful label seed was not included.

2002-03 to 2019-20 (Table 5). The quantity of seed certified, the area registered under seed production and the number of registered seed growers of both rice and other crops showed a progressive growth rate between 2002-03 and 2010-11 (Table 5). The major contributor to this growth is the dramatic progression in the seed replacement rate, which has rapidly grown from about 42 per cent to 88 per cent between 2001 and 2011 in the state (www.seednet.gov.in).

On the contrary, the same indicators showed negative growth rate in the subsequent period from 2010-11 to 2019-20, with the exception of the quantity of rice seed certified (0.12 %) and the total number of registered seed growers (0.26%), which shown a considerable improvement. The prime reason for negative growth rate in above indicators was due to most of private seed companies operating in the state are releasing the rice seed into market with truthful label (TL) rather than certified seed (CS). The important factor that influencing the companies to release the rice seed into market with TL was, majority of rice seed is produced in the rabi season and sold in the next kharif period, which is a very small period of time to pursue certification in order to make rice seed accessible to the market, favouring the firms to go for self-certification with TL.

CONCLUSION

The size of global seed business increased by about 15% between 2012 and 2020, rising from US$45.2 billion to US$52.2 billion. As a result, the share of India in the global seed business has increased from about 4 to 6 per cent during the same period. Further, the seed business in India has almost doubled during the past decade due to an increase in seed replacement rates (use of quality seeds) for open-pollinated crops and wide usage of hybrid varieties for field crops, along with Bt cotton and vegetables hybrids. However, the relative share of Telangana in the Indian seed business has declined from about 30 per cent to 19 per cent between 2014 and 2020 respectively. The reason for this change is that a sizeable portion of the seed industry has been shifted to Chhattisgarh in the case of hybrid rice seed production, to Karnataka in the case of BT cotton seed production, and to Andhra Pradesh in the case of hybrid maize seed production. However, a positive compound annual growth rate has been found in the distribution of all crops in India as well as in Telangana state over the last 2 decades, with deceleration in growth rates in recent period. The substantial increase in SRR (about 90 %) of all crops especially paddy in the recent past are the prime reasons for registering considerable growth in distribution of certified seed. Noteworthy to observe that the relative shares of seed production area under hybrid rice and BT cotton hybrids to total area under seed production fell from about 23 per cent to 13.35 per cent and 8 per cent to 4.75 per cent respectively between 2014 and 2020. However, total area under seed production for all crops, seed growers increased substantially in the state between this period. The trends of seed industry in Telangana in recent years suggest that there is a need to provide incentive oriented environment for seed growers in order to prevent further shifting of hybrid rice and Bt cotton seed production to other states.

Keeping in view, huge employment potential for rural youth and favourable production environment, the state government should formulate a comprehensive seed production policy to promote seed industry in the state.

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MAIZE PRICE TRANSMISSION BETWEEN MAJOR MARKETS IN TELANGANA STATE – AN ECONOMETRIC ANALYSIS

M. MAHESHNATH[1], R. VIJAYA KUMARI[2], K. SUHASINI[1], D. SRINIVASA REDDY[3] and A. MEENA[4]
[1]Department of Agricultural Economics, College of Agriculture, PJTSAU, Hyderabad
[2]Deputy Director of Research, PJTSAU, Hyderabad
[4]Cost of Cultivation Scheme, PJTSAU, Hyderabad
[5]Department of Statistics & Mathematics, College of Agriculture, Rajendranagar, Hyderabad

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ABSTRACT

This study tests long-run spatial market integration between price pairs of maize in five major markets *viz*., Badepally, Siddipet, Nagarkurnool, Warangal and Nizamabad of the Telangana State by adopting important econometric tools like Johansen's multivariate co integration approach, Augmented Dickey-Fuller (ADF), Granger causality test and Vector Error Correction Model (VECM). The study has confirmed the presence of co integration, implying the six years price association among the markets. To get the additional evidence as to whether and in which direction price transmission is occurring between the market pairs, Granger causality test has been used, which has confirmed Nizamabad to be the price-determining market. Nizamabad has been found comparatively more efficient as it has depicted most bidirectional causal relations with other markets. The Vector Error-Correction Model (VECM) shown the selected markets of maize are employed to know the speed of adjustments for the prices of maize among selected markets, for short run and long run equilibrium of prices. The results show that Badepally, Nizamabad and Warangal market influence prices in the other two major markets i.e., Siddipet and Nagarkurnool.

Key words: Market Integration, Maize, Co integration, Granger Causality, VECM

Telangana State is situated in the Deccan Plateau in Central India, officially created as twenty ninth state of India after bifurcation of erstwhile Andhra Pradesh in June 2014. Agriculture is the backbone of the state's economy that contributes to about 16 per cent to state's GDP and provide livelihood to 56 per cent of its population. Telangana state has witnessed its highest crop production of 1.3 crore metric tonnes during 2019-20 (http://des.telangana.gov.in) due to increase in area under cultivation because of irrigation projects such as Kaleshwaram and good rainfall.

Maize (*Zea mays* L.) known as Queen of Cereals, belongs to the grains family *Graminae*, also called corn was one of the first plants cultivated by farmers between 7,000 and 10,000 years ago. In India, maize crop standup as the third cash crop after wheat and rice. It is an important crop to India as 15 million Indian farmers are engaged in maize cultivation. States such as Karnataka, Rajasthan, Madhya Pradesh and Telangana contribute towards half of the total maize acreage in the country.

Maize is next to rice among the cereal crops and third top most crop among all the crops cultivated in Telangana with an area of 6.44 lakh hectares under cultivation. The maize production in Telangana was 17.51 lakh tonnes with an average yield of 3,057 Kg/ ha during the year 2019-20. Major maize growing districts in Telangana are Warangal Rural, Khammam, Nirmal, Siddipet, Kamareddy, Mahabubabad, Nizamabad, Warangal Urban, Jagityal and Karimnagar. Area and production of maize has increased manifolds in the state during the last one decade.

Price instability, exploitation of farmers by middlemen in marketing activities and lack of market integration system, etc. are few of the pressing problems faced by the farmers cultivating maize. Keeping this in view, Telangana Government has urged the farmers not to go for maize cultivation during *kharif* 2020-21 under the Regulated farming policy. Accordingly maize acreage has reduced from 4.09 lakh hectares to 2.93 lakh hectares in Telangana State even though the agro-climatic conditions are favourable for its cultivation.

Under these circumstances, it is felt that there is need to formulate appropriate ways and means for sustenance of the crop in the state and reduce price fluctuations, such that both producer's profit and

Email: imaheshnath@gmail.com

consumer's benefits will increase and lead for overall economic development of the state.

Jyothi *et al.* (2017) in their study investigated the relationship between spot and future market prices of maize and analysed the nature of price discovery process in India's maize futures market. They used unit root test to find out the stationarity of data set, co-integration and Granger-Causality test to analyse the long run and short run relationship respectively between maize futures and spot market prices. Seth and Sidhu (2018) studied price discovery and volatility spillovers in Indian wheat market. Granger-Causality test confirmed the existence of bidirectional causality between wheat spot and its underlying wheat futures market. From the study, Johansen co-integration test was found to approve the long-term equilibrium relationship between wheat spot and wheat futures prices. The Vector Error Correction Method showed that wheat futures market was found to lead wheat spot market in price discovery process in the long-run. Vasudev *et al.* (2015) conducted a study to assess the performance of the selected agricultural markets for maize in Telangana state. Correlation and co-integration analyses were carried out to determine the spatial market integration among the various maize markets. For co-integration analysis, the time series data were tested using the Dickey-Fuller unit root test followed by Engle-Granger test to determine the market integration. The results of analysis revealed that a moderate correlation ranging from 0.666 among Warangal - Nagarkurnool to 0.868 between Nizamabad - Siddipet for maize and all of them were significant at 1 per cent level of significance. Goletti and Babu (1994) studied the extent of market integration of maize markets in Malawi in order to understand how it has been affected by market liberalization. Several measures of integration are introduced to analyze both the co-movement of prices and the price adjustment process over time. Monthly retail prices of maize at eight main locations over the period January 1984 to December 1991 are considered. The main conclusion is that liberalization has increased market integration. Campiche *et al.* (2007) studied the relation between crude oil prices and variation of agricultural commodities using a vector error correction model. Co integration results denote that corn and maize prices are co integrated with crude oil price during the 2006-2007 time frames. Awal and Sabur (2009) examined the pricing efficiency of exportable fresh vegetables markets in Bangladesh and its export markets by using Engle-Granger (EG) test, Co integration Regression for Durbin Watson (CRDW) test and Error Correction Methods (ECM). Zhang *et al.* (2010) used the VEC model and the Granger test on the monthly data from 1989 to 2008 and reported that there is not any long run and short-run causality between the fuel (oil, gasoline and ethanol) and agricultural commodity (corn, maize, wheat, sugar and rice) prices. Nazlioglu and Soytas (2012) investigated the relationship between the world oil prices and the agricultural commodity prices by using the monthly data from 1980 to 2010 and the panel co-integration and the Granger causality techniques. The results of their study showed that the change in oil prices and the weak dollar have a strong impact on many agricultural commodity prices. Esposti and Listorti (2013) investigate on national and international markets; trade policy regime has an important role in price transmission mechanisms and the trade policy intervention put forward to mitigate the impact of price exuberance is considered. The authors analyzed agricultural price transmission during price bubbles, in particular, considering Italian and international weekly spot (cash) price data over years 2006–2010.

MATERIAL AND METHODS

For price integration, simple bivariate correlation coefficients measure price movements of a commodity in different markets. This is the simplest way to measure the spatial price relationships between two markets. Early inquiries on spatial market integration, for example Lele (1967) and Jones (1968) have used this method. However, this method clearly has some limitations, as it cannot measure the direction of price integration between two markets. The cointegration procedure measures the degree of price integration and takes into account the direction of price integration. This econometric technique provides more information than the correlation procedure, as it allows for the identification of both the integration process and its direction between two markets.

Market Integration Test

Market integration is tested using the cointegration method, which requires that

- Two variables, say P_{it} and P_{jt} are non-stationary in levels but

Stationary in first differences i.e.,

$$P_{it} \sim I(1) \text{ and } P_{jt} \sim I(1)$$

- There exists a linear combination between these two series,

Which is stationary i.e.

$$\varepsilon_{it} \; (= P_{it} - \hat{\alpha} - \hat{\beta} P_{jt}) \sim I\ (0)$$

So the first step is to test whether each of the univariate series is stationary. If they are both *I* (1) then we may go to the second step to test cointegration. The Engle and Granger (1987) procedure is the common way to test cointegration.

Unit root test

The regression analysis of non-stationary time series produces spurious results, which can be misleading (Ghafoor, *et al.,* 2009). The most appropriate method to deal with non-stationary time series for estimating long-run equilibrium relationships is cointegration, which necessitates that time series should be integrated of the same order. Augmented Dickey- Fuller (ADF) and Phillips-Perron test (PP) is used to verify the order of integration for each individual series. The ADF test, tests the null hypothesis of unit root for each individual time series. The rejection of the null hypothesis indicates that the series is non-stationary and *vice-versa* (Dickey and Fuller, 1981). The number of the appropriate lag for ADF is chosen for the absence of serial correlation using Akaike Information Criterion (AIC). The ADF test is based on the Ordinary Least Squares (OLS) method and requires estimating the following model.

$$\Delta \ln P_t = \alpha_0 + \delta_1 t + \gamma \ln P_{t-1} + \sum_{j=1}^{q} \vartheta_j \Delta \ln P_{t-j} + \varepsilon_t$$

Where, P the price in each market, Ä is the difference parameters (i.e., ÄP1 = $P_t - P_{t-1}$, $P_{t-1} = P_{t-1} - P_{t-2}$ and $P_{n-1} = P_{n-1} - P_{n-2}$) and so on, α_0 is the constant or drift, *t* is the time or trend variable, *q* is the number of lags length and ε_t is a pure white noise error term.

Johansen Cointegration

The maximum likelihood (ML) method of cointegration is applied to check long-run wholesale prices relation between the selected markets of Telangana (Johansen (1988); Johansen and Juselius, 1990). The starting point of the ML method is vector autoregressive model of order (k) and may be written as:

$$P_t = \sum_{i=1}^{k} A_t P_{t-1} + \mu + \beta_t + \varepsilon_t : \quad (t=1, 2, 3 \ldots T)$$

Where, (n*1) denotes the vector of non-stationary or integrated at order one, i.e., I (1) prices series. The procedure for estimating the cointegration vectors is based on the Vector error correction model (VECM) representation given by:

$$\Delta P_t = \pi P_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \beta \mu_t + \varepsilon_t$$

Where,

Γ_i = -(I- π_i-.....,T); i=1,2,....k-1

π = - (I- π , -......... π_k)

Both Γ_i and π_i are the n*n matrixes of the coefficient conveying the short and long run information respectively, ì is a constant term, t is a trend, and ε_t is the n-dimensional vector of the residuals that is identical and independently distributed. The vector ΔP_t is stationary P_t is integrated at order one I(1) which will make unbalance relation as long as π matrix has a full rank of k. In this respect, the equation can be solved by inversing the matrix π^{-1} for Pt and as a linear combination of stationary variable (Kirchgässner, *et al.,* 2012). The stationary linear combination of the Pt determines by the rank of Ð matrix. If the rank r of the matrix Ï r=0 the matrix is the null and the series underlying is stationary. If the rank of the matrix Ï is such that 0 < rank of (Ï) = r < n then there are n × r cointegrating vectors. The central point of the Johansen's procedure is simply to decompose Ð into two n × r matrices such that Ð=áâ'. The decomposition of Ð implies that the â'Pt are r stationary linear combination.

Johansen and Juselius, (1990) proposed two likelihood ratio test statistics (Trace and Max Eigen test statistics) to determine the number of cointegrating vectors as follows:

$$J_{trace} = -T \sum_{i=r+1}^{N} \ln(1 - \hat{\lambda}_1)$$

$$\lambda_{max} = -T \ln(1 - \hat{\lambda}_{r+1})$$

Where, r is the number cointegrated vector, $\hat{\lambda}_1$ is the eigen value and λ_{r+1} is the $(r+1)^{th}$ largest squared eigen value obtained from the matrix Ï and the T is the effective number of observation. The trace statistics tested the null hypothesis of r cointegrating vector(s) against the alternative hypothesis of n cointegrating relations. The Max Eigen statistic tested the null hypothesis (r =0) against the alternative $(r+1)$.

Vector Error Correction Model (VECM)

If price series are I (1), then one could run regressions in their first differences. However, by taking first differences, we lose the long-run relationship that is stored in the data. This implies that one needs to use variables in levels as well. Advantage of the vector error correction model (ECM) is that it incorporates variables both in their levels and first differences. By doing this, VECM captures the short-run disequilibrium situations as well as the long-run equilibrium adjustments between prices. Even if one demonstrates market integration through cointegration, there could be disequilibrium in the short-run i.e. price adjustment across markets may not happen instantaneously. It may take some time for the spatial price adjustments. VECM can incorporate such short-run and long-run changes in the price movements.

A VECM formulation, which describes both the short-run and long-run behaviors of prices, can be formulated as:

$$\Delta P_{it} = \gamma_1 + \gamma_2 \Delta P_{jt} - \pi \hat{\vartheta}_{it-1} + \vartheta_{it}$$

In this model, γ_2 is the impact multiplier (the short - run effect) that measures the immediate impact that a change in P_{jt} will have on a change in P_{it}. On the other hand, π is the feedback effect or the adjustment effect that shows how much of the disequilibrium is being corrected, that is the extent to which any disequilibrium in the previous period effects any adjustment in the period of course and therefore from this equation we also have being the long-run response.

Granger Causality Test

If a pair of series is cointegrated then there must be Granger causality in at least one direction, which reflects the direction of influence between series (in our case prices). Theoretically, if the current or lagged terms of a time-series variable, say , determine another time-series variable, say , then there exists a Granger causality relationship between and , in which is Granger caused by . Bessler and Brandt (1982) firstly introduced this test into research on market integration to determine the leading market.

From the above analysis, the model is specified as follows:

$$\Delta P_{it} = \theta_{11}\Delta P_{it-1} + \ldots + \theta_{1n}\Delta P_{it-n} + \theta_{21}\Delta P_{jt-1} + \ldots \theta_{2n}\Delta P_{jt-n}$$
$$- \gamma_1(P_{it-1} - \alpha P_{jt-1} - \delta) + \varepsilon_{1t}$$

$$\Delta P_{jt} = \theta_{31}\Delta P_{jt-1} + \ldots + \theta_{3n}\Delta P_{it-n} + \theta_{41}\Delta P_{it-1} + \ldots \theta_{4n}\Delta P_{it-n}$$
$$- \gamma_2(P_{it-1} - \alpha P_{jt-1} - \delta) + \varepsilon_{2t}$$

The following two assumptions are tested using the above two models to determine the Granger causality relationship between prices.

$\theta_{21} = ... = \theta_{2n} = ... = \gamma_1 = 0$ (No causality from to)

$\theta_{41} = ... = \theta_{4n} = ... = \gamma_2 = 0$ (No causality from to)

RESULTS AND DISCUSSION

The price data consist of monthly modal prices of maize (Rs/qtl) in five major markets *viz.* Badepally, Siddipet, Nagarkurnool, Warangal and Nizamabad of the Telangana State using monthly maize prices over the period from January 2016 to December 2021. The data was taken from the websites of agriculture marketing department, Government of Telangana State http://tsmarketing.in/ and https://agmarknet.gov.in/ . The maize modal price trend of all the selected markets is presented in Figure 1, which shows the symmetric behavior in the movement of prices in all the selected markets except Nizamabad, The maximum modal price of Rs. 2345/quintal prevailed in Nizamabad and the minimum price was found in Nagarkurnool Rs. 973/ quintal.

Descriptive Statistics

Summary statistics result shows that the price of maize remained highly volatile in Nizamabad followed by Badepally as measured by coefficient of variation. Based on arrivals the Badepally is major market for maize in Telangana State and the prices are dependent upon the demand in the other markets. The highest average prices of maize were found in

Table 1. Summary Statistics of the monthly modal Prices for maize in major markets for Telangana from the period January, 2016 to December, 2021(in '/100 kg)

	Badepally	Siddipet	Nagarkurnool	Warangal	Nizamabad
Mean	1540.53	1525.94	1484.40	1551.00	1454.64
Median	1465.00	1431.50	1459.00	1477.00	1422.50
Maximum	2260.00	2145.00	2145.00	2338.00	2345.00
Minimum	1159.00	1150.00	973.00	1215.00	1069.00
Std. Dev.	272.19	263.83	258.18	262.88	282.62
CV	17.67	17.29	17.39	16.95	19.43

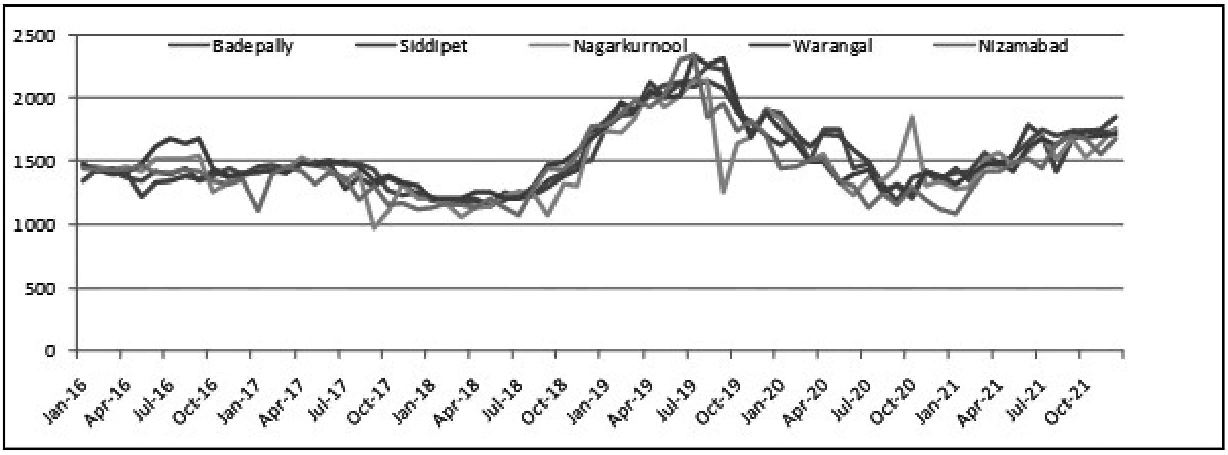

Fig. 1: Price behavior ('Rs/quintal) of maize crop in major selected markets in Telangana State

Table 2. ADF and PP Tests for Unit Root in the modal prices of Maize

Augmented Dickey-Fuller test results at original series				**Phillips-Perron test results at original series**		
	t-Statistic	**Prob.***	**Remarks**	**t-Statistic**	**Prob.***	**Remarks**
Badepally	-2.79	0.06	Non-stationary	-1.77	0.38	Non-stationary
Siddipet	-1.73	0.41	Non-stationary	-1.88	0.33	Non-stationary
Nagarkurnool	-3.46	0.01	Stationary	-3.25	0.02	Stationary
Warangal	-2.05	0.26	Non-stationary	-2.23	0.19	Non-stationary
Nizamabad	-2.10	0.24	Non-stationary	-2.04	0.26	Non-stationary
Augmented Dickey-Fuller test results after differencing				**Phillips-Perron test results after differencing**		
ΔBadepally	-9.20*	0.00	Stationary	-9.21*	0.00	Stationary
ΔSiddipet	-9.75*	0.00	Stationary	-9.72*	0.00	Stationary
ΔWarangal	-9.04*	0.00	Stationary	-9.06*	0.00	Stationary
ΔNizamabad	-10.69*	0.00	Stationary	-10.68*	0.00	Stationary

Note: * denote significance at 1% levels of significance and Ä denote the first difference of the time series.

Nizamabad market, while lowest average prices were in Nagarkurnool market, (Table 1).

Order of the Integration

In order to check the stationarity of price series of maize, the standard ADF and PP unit root tests, are applied to determine the order of integration. The unit root test regression implies that regressing the first difference of a series with its one period lag and several lags (as suggested by the various lag length criterion) of the first differenced series. The null hypothesis of

Table 3. Johansen's Co-integration Test Results of five major maize market prices in Telangana State

Hypothesized No. of CE(s)	Eigen value	Trace Statistics results			Max-Eigen Statistics results		
		Trace Statistics	0.05 Critical Value	P-Value	Max-Eigen Statistic	0.05 Critical Value	P-Value
None *	0.64	233.31	69.81	0.000*	81.98	33.87	0.000*
At most 1*	0.53	151.33	47.85	0.000*	61.26	27.58	0.000*
At most 2 *	0.45	90.06	29.7	0.000*	48.4	21.13	0.000*
At most 3 *	0.35	41.65	15.49	0.000*	34.99	14.26	0.000*
At most 4 *	0.07	6.65	3.84	0.009*	6.65	3.84	0.009*

Notes: in represent the natural logarithm and * denote the rejection of null hypothesis at 5% level of significance

Tables 4. Market pair wise results of the Granger Casualty test

Lagged Periods	Markets Pairs	F-Statistic	P-Value	Decision of null hypothesis	Remarks
1	Nagarkurnool - Badepally	**9.13 ****	**3.E-05**	**Do not reject**	**Unidirectional**
	Badepally - Nagarkurnool	1.16	0.32	Reject	No causality
2	Nizamabad - Badepally	**18.31 ****	**6.E-09**	**Do not reject**	**Bi-directional**
	Badepally - Nizamabad	**3.92 ****	**0.01**	**Do not reject**	
3	Siddipet - Badepally	**4.33 ****	**0.00**	**Do not reject**	**Unidirectional**
	Badepally - Siddipet	1.42	0.24	Reject	No causality
4	Warangal - Badepally	1.31	0.27	Reject	No causality
	Badepally - Warangal	1.13	0.33	Reject	No causality
5	Nizamabad - Nagarkurnool	**8.14 ****	**9.E-05**	**Do not reject**	**Unidirectional**
	Nagarkurnool - Nizamabad	1.59	0.19	Reject	No causality
6	Siddipet - Nagarkurnool	1.35	0.26	Reject	No causality
	Nagarkurnool - Siddipet	1.79	0.15	Reject	No causality
7	Warangal - Nagarkurnool	**4.12 ****	**0.00**	**Do not reject**	**Bi-directional**
	Nagarkurnool - Warangal	**5.15 ****	**0.00**	**Do not reject**	
8	Siddipet - Nizamabad	**2.79 ***	**0.04**	**Do not reject**	**Bi-directional**
	Nizamabad - Siddipet	**7.88 ****	**0.00**	**Do not reject**	
9	Warangal - Nizamabad	**4.02 ****	**0.01**	**Do not reject**	**Bi-directional**
	Nizamabad - Warangal	**11.63 ****	**3.E-06**	**Do not reject**	
10	Warangal - Siddipet	0.76	0.51	Reject	No causality
	Siddipet - Warangal	1.77	0.16	Reject	No causality

Note: * and ** represents the level of significance at 5% and 1% level

ADF and PP tests is accepted or rejected based on the critical value and corresponding probability value. If the test statistics is smaller in absolute terms than the critical values and the corresponding probability value is greater than 5% level, the series is said to be non-stationary. The results of the ADF and PP test values are below the critical value at 5% level of significance indicating the non existence of unit root test. This implies that the maize price series of Nagarkurnool market was stationary at original series and remaining four markets are non stationary at original series in all the major markets in Telangana State are Badepally, Siddipet, Warangal and Nizamabad. All the major markets i.e., Badepally, Siddipet, Warangal and Nizamabad are stationary at first difference I (1).

Co-integration Analysis

Johansen's Co-integration test for selected maize markets for the long-run co-integration was performed. If two series are potentially co-integrated, at least one co-integration relationship exists. Co-integration may be affected by some facts, such as transportation cost, tariffs, and so on. Two tests, i.e., trace and max Eigen statistics of Johansen's approach based on the vector autoregressive model (VAR) were put into the application to analyze the co- integrating vectors between the selected maize markets. The results of Johansen's maximum likelihood tests (maximum eigen-value and trace test) are reported in Table 3. The null hypothesis statement of existence of *r* co-integrated relationship against the alternative hypothesis of *r* +1 co-integration relationship was tested. Johansen (1988) ; Johansen and Juselius (1990) has given new technique for co-integration for long run as well as short run relationships for multivariate equation.

Granger causality test

After confirming the integration of price series, we have performed pair-wise Granger causality test for five major maize markets to comprehend causal relation between them. The result of the Granger causality analysis presented in Table 4 explicates that bidirectional causality market pairs were Nizamabad-Badepally, Warangal-Nagarkurnool, Siddipet-Nizamabad and Warangal-Nizamabad. In these cases, the former market in each pair granger causes the modal price formation in the latter market, which in turn provides the feedback to the former market as well. and unidirectional causality markets pairs were Nagarkurnool-Badepally, Siddipet-Badepally and Nizamabad-Nagarkurnool. It means that a price change in the former market in each pair granger cause the price formation in the latter market. Whereas all the remaining markets showed no causality. It means the price change in the latter market was not fed back for the price change in the former market.

Table 5. Vector Error Correction Model for Maize prices for Major five selected markets in Telangana State

Error Correction:	Badepally	Siddipet	Nagarkurnool	Warangal	Nizamabad
CointEq1	**[-7.07264]**	**[-3.14743]**	[-0.20222]	**[-4.00340]**	**[4.92785]**
Badepally(-1)	[-0.58332]	**[2.13296]**	[-0.51192]	**[2.80793]**	**[-2.41983]**
Badepally (-2)	[-1.81606]	[0.85566]	[-1.35395]	[1.47184]	**[-2.06747]**
Siddipet(-1)	[-1.70014]	**[-7.48715]**	**[-2.77929]**	[-0.48062]	[-0.35187]
Siddipet(-2)	[-0.67454]	**[-3.69358]**	[-0.07656]	[-1.02061]	[0.47698]
Nagarkurnool(-1)	[0.48385]	[-1.82981]	**[-6.41732]**	[-0.21537]	**[3.05408]**
Nagarkurnool(-2)	[0.46534]	[-1.42921]	**[-3.20264]**	[1.02273]	[1.07269]
Warangal(-1)	**[3.79717]**	[0.88807]	[0.10026]	**[-4.69624]**	**[-5.30175]**
Warangal(-2)	**[2.37556]**	[0.81185]	**[-2.38890]**	**[-2.11406]**	**[-2.64830]**
Nizamabad(-1)	**[-5.27571]**	**[-2.46613]**	[0.97150]	**[-2.84681]**	[1.08528]
Nizamabad(-2)	**[-4.15179]**	[-1.23934]	[1.47040]	**[-2.21829]**	[0.44260]
C	[-0.12684]	[0.02514]	[0.04087]	[-0.05906]	[0.04412]

Short run and long run behavior of market prices

Since the Johansen's multiple co-integration test results showed that the selected maize markets were having long run equilibrium relationship and so there exists co-integration between them. Hence the Vector Error Correction model (VECM) among the selected markets of maize is employed to know the speed of adjustments for the prices of maize among selected markets, for short run and long run equilibrium of prices. The results of VECM are presented in Table 5.

The estimates of Vector Error Correction Model revealed that co-integration equation value of Badepally, Siddipet, Warangal and Nizamabad markets attain short run equilibrium rapidly. Badepally market one month lag price was affecting current prices of Siddipet, Warangal and Nizamabad markets. Siddipet market one month lag price was affecting current prices of Nagarkurnool and Siddipet markets.

Nagarkurnool market one month lag price was affecting current prices of Nagarkurnool and Nizamabad markets. Nizamabad market one month lag price was affecting current prices of Badepally, Siddipet and Warangal markets. Warangal market one month lag price was affecting current prices of Badepally, Warangal and Nizamabad markets. Two month lag price of Badepally market was affecting Nizamabad market current price. Two month lag price of Nagarkurnool market was affecting Nagarkurnool market current price. Two month lag price of Nizamabad market was affecting Badepally and Warangal market current prices. Two month lag price of Siddipet market was affecting Siddipet market current price. Two month lag price of Warangal market was affecting Badepally, Nagarkurnool, Warangal and Nizamabad market current prices.

CONCLUSION

This study investigated the spatial market integration and price behavior of maize markets through co-integration analysis in Telangana State using January, 2016 to December, 2021 modal monthly price data. All major markets of maize in the Telangana State were found to be highly integrated with regard to price movement. Agricultural markets play an important role in agricultural marketing and production efficiency. A fundamental issue when analyzing policy reform with regards to national agricultural markets is the extent to which domestic agricultural commodity markets respond to price changes. The overall performance of agriculture depends, not only on efficiency of production or supply, but also on marketing efficiency, particularly the agricultural markets and price signal. Spatial market integration measures the extent to which markets at geographically distant locations (such as between regions) share common long-run price or trade information for a homogenous commodity. The results of ADF unit root test indicated that price series are stationary in first differencing logarithm except for Nagar kurnool market i.e., Badepally, Siddipet, Warangal and Nizamabad markets found to be integrated zero order I (1). Results of Johansen's co integration test showed the price series as co integrated. The results of the Granger causality analysis explicates that bidirectional causality market pairs were Nizamabad-Badepally, Warangal-Nagarkurnool, Siddipet-Nizamabad and Warangal-Nizamabad. A unidirectional causality markets pairs are Nagarkurnool-Badepally, Siddipet-Badepally and Nizamabad-Nagarkurnool. Results of Vector Error Correction Model (VECM) showed that Badepally market one month lag price was affecting current prices of Siddipet, Warangal and Nizamabad markets. Siddipet market one month lag price was affecting current prices of Nagarkurnool and Siddipet markets. Nagarkurnool market one month lag prices was affecting current prices of Nagarkurnool and Nizamabad markets. Nizamabad market one month lag price was affecting current prices of Badepally, Siddipet and Warangal markets. Warangal market one month lag price was affecting current prices of Badepally, Warangal and Nizamabad markets. Two month lag price of Badepally market was affecting Nizamabad market current price. Two month lag price of Nagarkurnool market was affecting Nagarkurnool market current price. Two month lag price of Nizamabad market was affecting Badepally and Warangal market current prices. Two month lag price of Siddipet market was affecting Siddipet market current price. Two month lag price of Warangal market was affecting Badepally, Nagarkurnool, Warangal and Nizamabad market current prices. This clearly indicates maize price transmission between major markets in Telangana State.

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