



## Research Article

# OPTIMAL DATE OF SOWING OF CROPS FOR MAXIMIZING YIELD, RAINWATER USE EFFICIENCY AND MONETARY RETURNS UNDER ARID ALFISOLS

SAHADEVA REDDY B.<sup>1</sup>, RAVINDRANATHA REDDY B.<sup>2</sup> AND RADHA KUMARI C.<sup>3</sup>

<sup>1</sup>Agricultural College, Rajahmundry, East Godavari, 533105, Acharya N. G. Ranga Agricultural University, Lam, Guntur, 522034, Andhra Pradesh

<sup>2,3</sup>AICRP for Dryland Agriculture, Agricultural Research Station, Anantapur, 515001, Acharya N. G. Ranga Agricultural University, Lam, Guntur, 522034, Andhra Pradesh

\*Corresponding Author: Email-sahadevardd@gmail.com

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**Abstract-** Ten crops viz., groundnut, castor, sorghum, pearl millet, foxtail millet, pigeonpea, green gram, cluster bean, field bean and cowpea were tested on 5 dates of sowing (D1: 1<sup>st</sup> fortnight (FN) of June; D2: 2<sup>nd</sup> FN of June; D3: 1<sup>st</sup> FN of July; D4: 2<sup>nd</sup> FN of July; D5: 1<sup>st</sup> FN of August) for 6 years during 2009 to 2014 with the objective of identifying an optimal sowing date for crops to attain maximum groundnut equivalent yield (kg ha<sup>-1</sup>), rainwater use efficiency (RWUE, kg ha<sup>-1</sup>mm<sup>-1</sup>), gross returns (Rs ha<sup>-1</sup>) and benefit-cost ratio (BCR) under arid Alfisols at Anantapur in south India. Significant correlation existed among crop seasonal rainfall, crop growing period, groundnut equivalent yield, rainwater use efficiency, gross returns and benefit-cost ratio in different years. The groundnut equivalent yield was significantly higher when crops were sown in D1 at the onset of monsoon and decreased when sown in D2, D3, D4 and D5 at 15-day interval. Among 5 dates of sowing, sowing of crops done in D1 gave mean groundnut equivalent yield of 492 kg ha<sup>-1</sup>, RWUE of 2.67 kg ha<sup>-1</sup> mm<sup>-1</sup>, gross returns of Rs.28059 ha<sup>-1</sup> and BCR of 2.04; while D2 gave groundnut equivalent yield of 469 kg ha<sup>-1</sup>, RWUE of 2.86 kg ha<sup>-1</sup>mm<sup>-1</sup>, gross returns of Rs.26726 ha<sup>-1</sup> and BCR of 1.99. The ranking of crops for different parameters and their rank sum for each date of sowing indicated the superiority of castor when sown on D1, D2 and D4, while cowpea was superior on D3 and D5 with lowest rank sum. Groundnut was superior for pod yield and gross returns when sown on D1, D2, D3 and D4, while field bean was superior on D5. Castor was superior for benefit-cost ratio on D1 and D2; while green gram was superior on D3 and D4; and cowpea was superior on D5. Pearl millet was superior for RWUE on all dates of sowing. Castor attained 1<sup>st</sup> rank on D1, D2 and D4; 2<sup>nd</sup> rank on D3; and 4<sup>th</sup> rank on D5; while cowpea attained 1<sup>st</sup> rank on D3 and D5; 2<sup>nd</sup> rank on D1 and D2; and 3<sup>rd</sup> rank on D4. Thus, castor and cowpea were efficient on D1, D2 and D3, while castor and green gram were efficient on D4, and cowpea and field bean were efficient on D5. We recommend castor and cowpea as alternative crops to groundnut for attaining maximum yield, monetary returns and rainwater use efficiency under arid Alfisols.

**Key words-** Date of sowing, Crop seasonal rainfall, Crop growing period, Groundnut equivalent yield, Rainwater use efficiency, Gross returns, Benefit-cost ratio.

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## Introduction

Two thirds of cultivated area in India is under rainfed farming which is often influenced by aberrant weather conditions. Rainfed regions make a major contribution to pulses, oilseeds and millet production [1]. Due to erratic rainfall conditions, rainfed farmers would often suffer by attaining low productivity and meager net returns from different crops. The erratic rainfall and its variability has frequently affected the productivity of groundnut and other crops at Anantapur in Andhra Pradesh. Among different factors, optimum date of sowing is an important determinant of crop yield and monetary returns when occurrence of rainfall is erratic. The sowing date of a crop would often depend on the onset of monsoon, quantity and distribution of rainfall [2]. The delayed sowing of groundnut beyond July would significantly reduce the pod yield by about 70% under dryland conditions (Reddy *et al.*, 1984) [3]. In dryland agriculture, moisture is the most crucial input for crop production. The biotic and abiotic stresses such as prolonged and recurring dry spells during crop growth period would further add to the woes of rainfed farmers. Maruthi Sankar *et al.*, (2012b) [4] studied the effects of rainfall received in different months from sowing to harvest on pearl millet yield under different soil and agro-climatic conditions. Based on crop and weather relationships, Nema, *et al.*, (2008) and Ladda, *et al.*, (2010) [5,6] have observed the effect of erratic rainfall distribution and moisture stress on the productivity of cereal crops.

Padmani, *et al.*, (2009) [7] identified superior crop rotations which maximized productivity and monetary returns under erratic rainfall conditions in semi-arid Vertisols. However, an optimum sowing date is essential for any crop to attain maximum yield and monetary returns under any soil and agro-climatic condition. About 61% of rainfall is normally received during south-west monsoon period (June to September) under arid Alfisols at Anantapur. The deficiency and erratic distribution of rainfall would often lead to either delayed sowings or stress at different stages of crops which would lead to crop failure. Though the long-term mean annual rainfall of Anantapur is about 550 mm, the district received as low as 200 mm in below normal years and as high as 900 mm in above normal years. The monsoon would occur in the first week of June and often get delayed even up to end of August. There is a high variation for the onset date which is typical feature of the district and is a major cause of uncertainty in rainfed farming. The length of crop growing period from sowing to harvest would vary depending on the onset, number of rainy days and withdrawal of monsoon in any season [8]. The erratic onset of monsoon and commencement of sowing rains would force the farmers to sow a crop under late monsoon condition [9]. In this study, 10 crops were tested on 5 dates of sowing done at 15-day interval for 6 years during 2009 to 2014 with the objective of identifying an optimal date of sowing for attaining maximum yield, monetary returns and rainwater use efficiency under arid Alfisols.

**Materials and Methods**

**Experimental details**

Field experiments were conducted on 10 crops on 5 dates of sowing during *kharif* 2009 to 2014 at Anantapur under arid Alfisols located in the scarce rainfall zone of Andhra Pradesh at a latitude of 14°41' N, longitude of 77°40' E and altitude of 350 meters above mean sea level. The crops (varieties) comprised of 3 cereals viz., sorghum (NTJ-4), pearl millet (Siri) and foxtail millet (Srilakshmi); 2 oilseeds viz., groundnut (K-6) and castor (Haritha); and 5 legumes viz., pigeonpea (LRG-41), green gram (ML-267), cowpea (Co-4), field bean (TFB-2) and cluster bean (RGC-1025). The crops were sown with the receipt of rainfall in the 5 dates of sowing at an interval of 15 days. The sowing dates were (i) 1<sup>st</sup> fortnight of June (D1); (ii) 2<sup>nd</sup> fortnight of June (D2); (iii) 1<sup>st</sup> fortnight of July (D3); (iv) 2<sup>nd</sup> fortnight of July (D4); and (v) 1<sup>st</sup> fortnight of August (D5). The field experiments were conducted by adopting dates of sowing (DOS) in main plots and crops in sub-plots in a split-plot design with 3 replications. The study was conducted in a red sandy loam soil which is near neutral in reaction (pH of 6.9), low in organic carbon (0.27%), soil N (63 kg ha<sup>-1</sup>) and soil K (91 kg ha<sup>-1</sup>) and high in soil P (107 kg ha<sup>-1</sup>). Sorghum and pearl millet had a row x plant spacing of 45 x 15 cm; while foxtail millet, green gram, cluster bean and groundnut had a spacing of 30 x 10 cm; cowpea had a spacing of 45 x 20 cm; field bean had a spacing of 60 x 30 cm; pigeonpea had a spacing of 90 x 20 cm and castor had a spacing of 90 x 60 cm in every year. The recommended fertilizer NPK dose of 20-4-50 kg ha<sup>-1</sup> to cowpea, field bean, cluster bean and groundnut and 20-50-0 kg ha<sup>-1</sup> to pigeonpea and green gram were applied every year. Similarly, the recommended doses of 60-40-30 kg ha<sup>-1</sup> to sorghum, 60-30-20 kg ha<sup>-1</sup> to pearl millet, 40-30-0 kg ha<sup>-1</sup> to foxtail millet and 50-40-30 kg ha<sup>-1</sup> to castor were applied every year. The recommended seed rate of 4 kg ha<sup>-1</sup> to pearl millet; 5 kg ha<sup>-1</sup> to foxtail millet, pigeonpea and castor; 8 kg ha<sup>-1</sup> to

sorghum; 10 kg ha<sup>-1</sup> to field bean and cluster bean; 15 kg ha<sup>-1</sup> to green gram; 20 kg ha<sup>-1</sup> to cowpea and 150 kg ha<sup>-1</sup> to groundnut were adopted every year as described by Vittal, *et al.*, (2003b) [10].

**Rainfall and its distribution from sowing to harvest of crops**

The onset of monsoon occurred on 1<sup>st</sup> June in 2009 and 2010, 4<sup>th</sup> June in 2011 and 2013, 15<sup>th</sup> June in 2014 and 16<sup>th</sup> June in 2012; while withdrawal of monsoon was on 16<sup>th</sup> October in 2013, 17<sup>th</sup> October in 2014, 18<sup>th</sup> October in 2012, 22<sup>nd</sup> October in 2010, 24<sup>th</sup> October in 2011 and 29<sup>th</sup> October in 2009. The number of rainy days were 24 in 2009, 34 in 2010, 22 in 2011, 28 in 2012, 8 in 2013 and 20 in 2014. The details of onset and withdrawal of monsoon, number of rainy days, crop seasonal rainfall, dates of sowing (DOS) and harvest (DOH) of crops are given in [Table-1]. The annual rainfall ranged from 375 mm in 2014 to 886 mm in 2010. Maximum crop seasonal rainfall (CRF) of 282, 606, 260, 299, 359 and 209 mm was available to crops when sown on D1 in 2009, 2010, 2011, 2012, 2013 and 2014 respectively. It reduced to 247, 213, 201 and 115 mm in 2009; 565, 591, 521 and 482 mm in 2010; 217, 229, 208 and 168 mm in 2011; 289, 226, 167 and 146 mm in 2012; 349, 308, 236 and 50 mm in 2013; and 199, 202, 116 and 72 mm in 2014 when sown on D2, D3, D4 and D5 respectively as depicted in [Fig-1]. The CRF of crops under different dates of sowing during 2009 to 2014 is given in [Table-2]. The mean rainfall received by crops over years on different dates of sowing is depicted in [Fig-2]. The mean (variation) rainfall over years was maximum of 296 mm (27.4%) for sorghum; followed by 291 mm (26.4%) for pigeonpea; 290 mm (27.2%) for field bean; 274 mm (25.9%) for groundnut; 269 mm (20.1%) for castor; 267 mm (15.6%) for cluster bean; 255 mm (20.6%) for pearl millet; 234 mm (17.5%) for green gram; 229 mm (15.5%) for foxtail millet; and 221 mm (13.4%) for cowpea. The CRF of crops indicated that there was a significant decrease in rainfall received from D1 to D5.

**Table-1** Dates of sowing and harvest of different crops during 2009 to 2014.

Date of sowing	Date of harvest of crops in different years									
	Sorghum	Pearl millet	Foxtail millet	Pigeonpea	Green gram	Cowpea	Field bean	Cluster bean	Groundnut	Castor
2009 : Monsoon onset = 1 <sup>st</sup> June; Monsoon withdrawal = 29 <sup>th</sup> October; Number of rainy days = 24; Crop seasonal rainfall = 270.6 mm										
D1 : 13-Jun	12-Nov	20-Sep	14-Oct	8-Feb	25-Aug	14-Oct	12-Jan	14-Oct	29-Oct	2-Nov
D2 : 17-Aug	7-Jan	25-Nov	15-Nov	16-Feb	27-Oct	2-Nov	12-Jan	12-Nov	8-Dec	2-Dec
D3 : 4-Sep	7-Jan	10-Dec	5-Dec	17-Feb	2-Dec	2-Dec	12-Jan	24-Nov	7-Jan	9-Mar
D4 : 22-Sep	20-Jan	27-Dec	20-Dec	9-Mar	16-Dec	22-Dec	17-Jan	20-Jan	19-Jan	9-Mar
D5 : 6-Oct	9-Feb	12-Jan	4-Jan	9-Mar	30-Dec	5-Jan	19-Jan	31-Jan	9-Feb	3-Apr
2010 : Monsoon onset = 1 <sup>st</sup> June; Monsoon withdrawal = 22 <sup>nd</sup> October; No. of rainy days = 34; Crop seasonal rainfall = 484.4 mm										
D1 : 5-Jun	18-Oct	25-Sep	15-Sep	28-Nov	9-Aug	13-Aug	28-Nov	14-Sep	29-Sep	5-Oct
D2 : 21-Jun	27-Oct	28-Sep	23-Sep	30-Dec	30-Aug	30-Aug	30-Dec	27-Sep	16-Oct	20-Oct
D3 : 9-Jul	10-Nov	4-Oct	5-Oct	17-Jan	28-Sep	17-Nov	17-Jan	4-Oct	27-Oct	26-Oct
D4 : 21-Jul	8-Dec	28-Oct	6-Nov	21-Feb	11-Oct	27-Nov	21-Feb	26-Oct	10-Nov	9-Dec
D5 : 14-Aug	28-Dec	20-Nov	8-Nov	24-Feb	9-Nov	26-Nov	24-Feb	27-Nov	29-Oct	12-Dec
2011 : Monsoon onset = 4 <sup>th</sup> June; Monsoon withdrawal = 24 <sup>th</sup> October; No. of rainy days = 22; Crop seasonal rainfall = 349.8 mm										
D1 : 2-Jun	1-Nov	20-Sep	Failed	29-Dec	8-Sep	14-Sep	29-Dec	17-Sep	28-Sep	20-Sep
D2 : 7-Jul	5-Nov	28-Sep	28-Sep	29-Dec	17-Sep	15-Sep	29-Dec	19-Sep	29-Oct	1-Oct
D3 : 26-Jul	29-Nov	18-Oct	27-Oct	1-Jan	13-Oct	10-Oct	29-Dec	1-Oct	24-Nov	22-Oct
D4 : 17-Aug	13-Dec	15-Nov	16-Nov	5-Jan	25-Oct	19-Oct	29-Dec	22-Oct	8-Dec	25-Nov
D5 : 2-Sep	7-Jan	1-Dec	1-Dec	16-Jan	20-Jan	3-Dec	29-Dec	25-Oct	14-Dec	20-Jan
2012 : Monsoon onset = 16 <sup>th</sup> June; Monsoon withdrawal = 18 <sup>th</sup> October; No. of rainy days = 28; Crop seasonal rainfall = 379.4 mm										
D1 : 27-Jun	17-Nov	5-Oct	3-Oct	3-Jan	17-Sep	24-Sep	10-Jan	17-Sep	5-Oct	15-Nov
D2 : 18-Jul	22-Nov	26-Oct	26-Oct	9-Jan	26-Oct	26-Oct	10-Jan	11-Oct	26-Oct	15-Nov
D3 : 23-Aug	17-Dec	12-Nov	14-Nov	17-Jan	7-Nov	17-Nov	10-Jan	7-Nov	12-Nov	3-Dec
D4 : 4-Sep	20-Dec	22-Nov	30-Nov	19-Jan	17-Dec	17-Dec	11-Jan	30-Nov	22-Nov	21-Dec
D5 : 29-Sep	5-Jan	14-Dec	19-Dec	24-Jan	22-Dec	22-Dec	11-Jan	14-Dec	14-Dec	24-Jan
2013 : Monsoon onset = 4 <sup>th</sup> June; Monsoon withdrawal = 16 <sup>th</sup> October; No. of rainy days = 8; Crop seasonal rainfall = 378.0 mm										
D1 : 6-Jun	15-Nov	18-Oct	5-Oct	4-Jan	5-Oct	6-Oct	8-Jan	1-Sep	7-Oct	25-Jan
D2 : 8-Jul	9-Dec	19-Oct	23-Oct	6-Jan	7-Oct	20-Oct	10-Jan	25-Sep	5-Nov	2-Feb
D3 : 23-Aug	11-Dec	18-Nov	17-Nov	30-Jan	8-Nov	1-Nov	11-Jan	23-Nov	24-Nov	5-Feb
D4 : 5-Sep	4-Jan	2-Dec	26-Nov	3-Feb	18-Nov	17-Nov	19-Jan	9-Dec	9-Dec	17-Feb
D5 : 17-Sep	22-Jan	13-Dec	9-Dec	11-Feb	22-Dec	24-Nov	20-Jan	9-Dec	13-Dec	19-Feb
2014 : Monsoon onset = 15 <sup>th</sup> June; Monsoon withdrawal = 17 <sup>th</sup> October; No. of rainy days = 20; Crop seasonal rainfall = 299.4 mm										
D1 : 4-Jun	27-Nov	21-Oct	5-Oct	8-Jan	30-Sep	30-Sep	3-Jan	16-Aug	1-Nov	7-Nov
D2 : 11-Jul	1-Dec	24-Oct	18-Oct	8-Jan	1-Oct	1-Oct	3-Jan	18-Oct	3-Nov	7-Nov
D3 : 22-Aug	16-Dec	10-Nov	21-Nov	20-Jan	12-Nov	10-Nov	3-Jan	21-Nov	5-Dec	2-Jan
D4 : 17-Sep	23-Dec	12-Dec	5-Dec	20-Jan	18-Nov	18-Dec	20-Jan	6-Dec	31-Dec	20-Jan
D5 : 10-Oct	19-Jan	23-Dec	30-Dec	16-Feb	23-Nov	23-Dec	20-Jan	31-Dec	19-Jan	7-Feb

**Table-2** Crop seasonal rainfall (mm) received from sowing to harvest of crops under 5 dates of sowing in different years.

Crops	D1	D2	D3	D4	D5	Mean	CV (%)
<b>2009</b>							
Sorghum	310	285	210	201	115	224	34.4
Pearl millet	234	205	209	201	115	193	23.6
Foxtail millet	234	205	209	201	115	193	23.6
Pigeonpea	325	285	231	201	115	231	35.0
Green gram	325	205	209	201	115	211	35.5
Cowpea	234	205	209	201	115	193	23.6
Field bean	325	285	210	201	115	227	35.9
Cluster bean	234	266	209	201	115	205	27.6
Groundnut	234	284	210	201	115	209	29.5
Castor	325	284	231	201	115	231	35.0
Mean	282	247	213	201	115	211	29.7
<b>2010</b>							
Sorghum	642	607	680	557	519	601	10.7
Pearl millet	579	511	498	455	515	511	8.7
Foxtail millet	540	502	498	586	446	514	10.1
Pigeonpea	783	711	698	559	519	654	16.9
Green gram	539	511	594	542	510	539	6.4
Cowpea	540	511	552	455	515	515	7.3
Field bean	783	711	698	559	519	654	16.9
Cluster bean	540	511	498	455	415	484	10.1
Groundnut	587	565	594	546	415	542	13.5
Castor	588	565	593	557	519	564	5.2
Mean	606	565	591	521	482	553	9.2
<b>2011</b>							
Sorghum	349	290	280	229	170	264	25.6
Pearl millet	231	172	222	216	170	202	14.3
Foxtail millet	231	172	224	216	170	202	14.5
Pigeonpea	363	304	281	230	170	269	27.2
Green gram	201	172	216	171	170	186	11.4
Cowpea	204	172	154	171	170	174	10.5
Field bean	363	304	280	229	170	269	27.3
Cluster bean	231	172	148	171	156	176	18.5
Groundnut	231	278	267	229	170	235	18.0
Castor	231	172	222	216	170	202	14.3
Mean	260	217	229	208	168	217	15.4
<b>2012</b>							
Sorghum	360	307	237	171	146	244	36.9
Pearl millet	301	276	222	155	146	220	31.5
Foxtail millet	301	276	222	161	146	221	30.8
Pigeonpea	375	322	237	171	146	250	39.0
Green gram	360	276	222	171	146	235	36.6
Cowpea	226	276	222	171	146	208	24.4
Field bean	375	322	237	171	146	250	39.0
Cluster bean	226	270	222	161	146	165	55.7
Groundnut	301	276	222	170	146	223	29.7
Castor	360	307	227	171	146	242	37.3
Mean	299	289	226	167	146	226	30.6
<b>2013</b>							
Sorghum	378	362	308	237	50	267	49.9
Pearl millet	347	332	308	237	50	255	47.9
Foxtail millet	347	351	308	232	50	258	48.7
Pigeonpea	378	362	308	232	50	266	50.2
Green gram	347	332	308	237	50	256	47.9
Cowpea	347	337	308	237	50	256	48.0
Field bean	378	362	308	237	50	267	49.9
Cluster bean	347	362	308	237	50	261	48.8
Groundnut	347	358	308	237	50	260	48.7
Castor	347	332	308	237	50	255	47.9
Mean	359	349	308	236	50	260	48.8
<b>2014</b>							
Sorghum	256	231	207	118	72	177	44.3
Pearl millet	197	174	199	118	72	152	36.4
Foxtail millet	181	170	199	110	72	146	36.4
Pigeonpea	264	238	207	118	72	180	45.4
Green gram	181	155	193	118	72	144	34.3
Cowpea	181	155	199	118	72	145	35.1
Field bean	264	238	207	118	72	180	45.4
Cluster bean	51	170	199	110	72	120	52.4
Groundnut	255	229	200	118	72	175	44.1
Castor	255	229	207	118	72	176	44.1
Mean	209	199	202	116	72	160	38.8
<i>Pooled</i>							

Sorghum	383	347	320	252	179	296	27.4
Pearl millet	315	278	276	230	178	255	20.6
Foxtail millet	268	239	241	226	172	229	15.5
Pigeonpea	387	340	297	238	195	291	26.4
Green gram	288	235	255	213	180	234	17.5
Cowpea	251	237	236	198	181	221	13.4
Field bean	388	341	296	236	191	290	27.2
Cluster bean	227	283	264	222	159	231	20.6
Groundnut	326	332	300	250	161	274	25.9
Castor	336	297	278	238	196	269	20.1
Mean	317	293	276	230	179	259	21.2

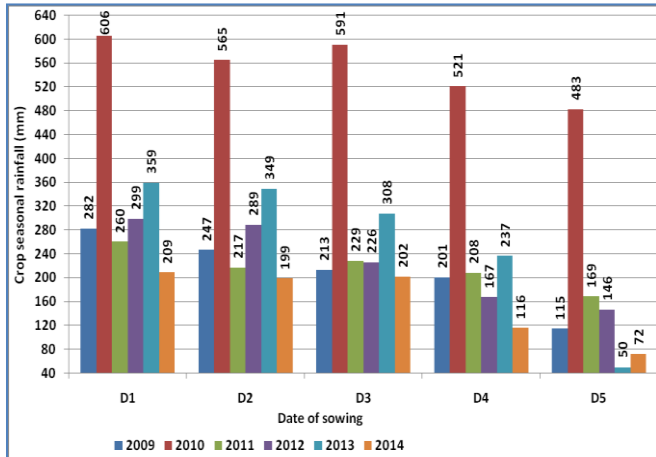


Fig-1 Mean crop seasonal rainfall (mm) received from sowing to harvest under different dates of sowing during 2009 to 2014.

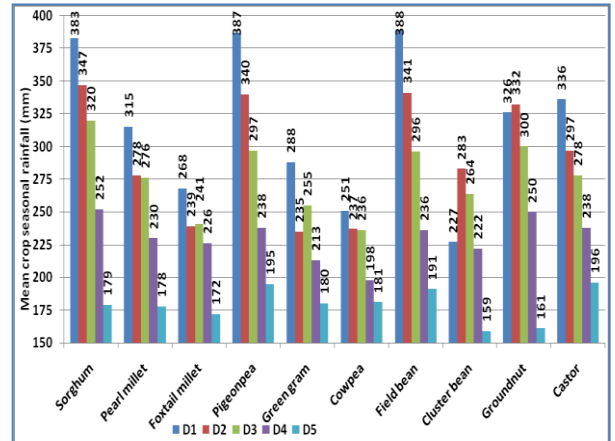
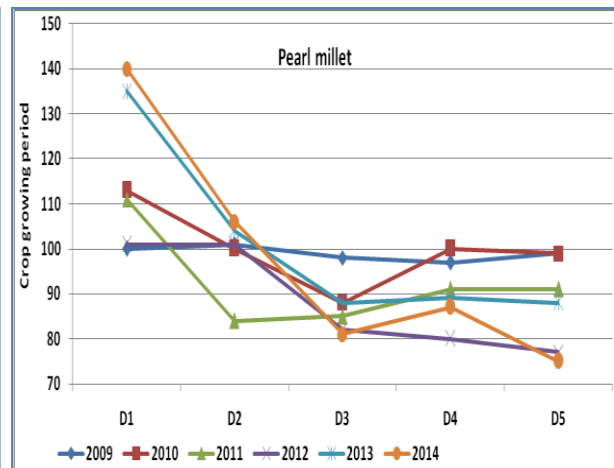
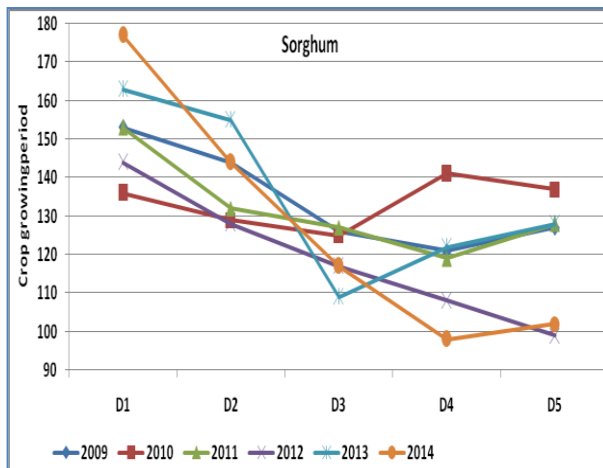


Fig-2 Crop-wise mean rainfall (mm) received from sowing to harvest under different dates of sowing during 2009 to 2014.

### Growing period of crops sown on different dates of sowing

The crop growing period (CGP) from sowing to harvest of crops during 2009 to 2014 is depicted in [Fig-3]. In 2009, green gram had minimum CGP of 74, 72, 90, 86 and 86 days on the 5 dates of sowing, while pigeonpea had maximum of 241, 184, 167 and 170 days when sown on D1, D2, D3 and D4 and castor had maximum of 180 days when sown on D5. In 2010, green gram had minimum CGP of 66, 71, 82 and 83 days on D1, D2, D3 and D4 compared to groundnut with 77 days on D5, while pigeonpea had maximum of 177, 193, 193, 216 and 195 days when sown on 5 dates of sowing. In 2011, green gram sown on D1 had minimum CGP of 99 days compared to cowpea with 81 days on D2 and 64 days on D4, cluster bean with 68 days on D3 and 54 days on D5. Pigeonpea had maximum duration of 211, 176, 160 and 142 days on first 4 dates of sowing, while green gram had maximum duration of 141 days when sown on D5. In 2012, minimum duration of 84 days on D1 and 77 days on D3 were maintained by green gram and cluster bean, 80 days on D4 by pearl millet and groundnut, while cluster bean

maintained 86 days on D2, cluster bean and groundnut maintained 77 days on D5. Field bean had maximum duration of 198 days when sown on D1 and 177 days on D2, while pigeonpea had maximum of 148, 138 and 118 days on D3, D4 and D5 respectively. In 2013, cluster bean had lowest duration of 88 days on D1 and 80 days on D2, compared to cowpea with 71, 74 and 69 days when sown on D3, D4 and D5 respectively, while castor had maximum duration of 234, 220, 167, 166 and 156 days on 5 dates of sowing respectively. In 2014, cluster bean had lowest duration of 74 days when sown on D1, while cowpea and green gram had 83 days on D2, pearl millet and cowpea had 81 days on D3, green gram had 63 days on D4 and 45 days on D5. Pigeonpea had maximum CGP of 219, 182, 152, 126 and 130 days on 5 dates of sowing respectively. When pooled over years, green gram had minimum CGP of 94, 84, 82 and 80 days on D1, D2, D3 and D4 compared to foxtail millet with 86 days on D5, while pigeonpea had maximum duration of 209, 182, 164, 157 and 147 days on 5 dates of sowing respectively.



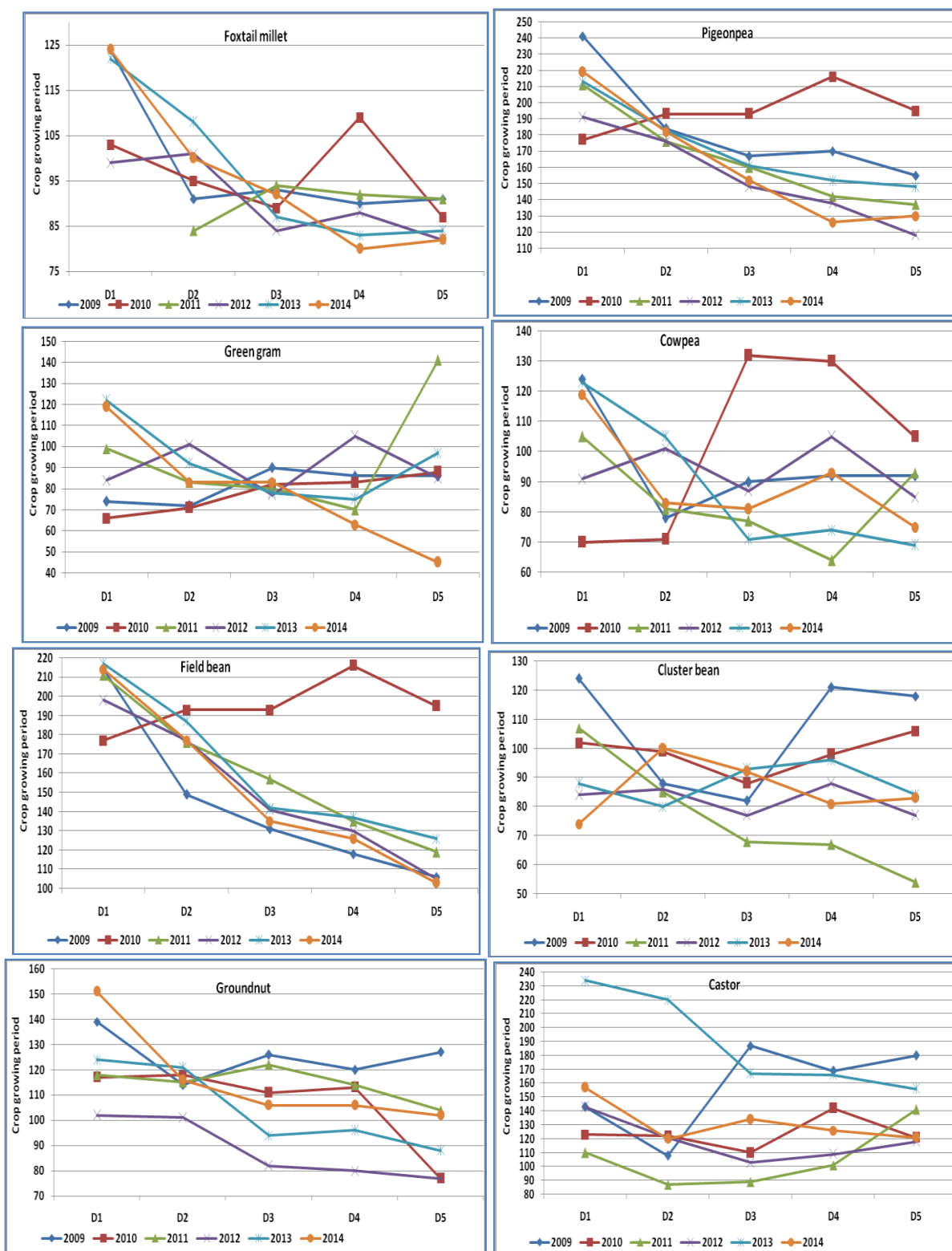


Fig-3 Growing period of crops sown on different dates of sowing during 2009 to 2014.

**Statistical analysis**

The field experiments were conducted with 10 crops on 5 dates of sowing with 3 replications in a split-plot design. The treatments were randomized only in the first year and were superimposed to same plots every year. Observations were collected from each plot on crop yield ( $\text{kg ha}^{-1}$ ) at harvest; rainwater use efficiency ( $\text{kg ha}^{-1}\text{mm}^{-1}$ ); cost of cultivation ( $\text{Rs ha}^{-1}$ ); gross monetary returns ( $\text{Rs ha}^{-1}$ ); net monetary returns ( $\text{Rs ha}^{-1}$ ); and benefit-cost ratio and were statistically analyzed. The gross monetary returns ( $\text{Rs ha}^{-1}$ ) were derived based on seed and stalk yield using prevailing market prices in each season. The main and first-order interaction effects were tested based on F-test under standard analysis of variance (ANOVA)

procedure. The differences in groundnut equivalent yield and monetary returns attained by crops on different dates of sowing were compared based on Least Significant Difference (LSD) criteria by Gomez and Gomez, (1984) [11]. The superiority of crops sown on different dates of sowing was assessed and inferences drawn about optimal date of sowing for crops under varying rainfall conditions. The rainwater use efficiency (RWUE,  $\text{kg ha}^{-1}\text{mm}^{-1}$ ) was derived as ratio of groundnut equivalent yield ( $\text{kg ha}^{-1}$ ) attained by a crop and crop seasonal rainfall (mm) of respective crop in each year and averaged over years as described by Rockstrom, *et al.*, (2003) and Maruthi Sankar, *et al.*, (2013) [12, 2]. The cost of cultivation of each crop was determined by taking into account inputs

like seed and fertilizer costs and agricultural operations from sowing to harvest. The gross returns were computed as a product of yield of a crop and its market price (Rs kg<sup>-1</sup>). The benefit-cost ratio was computed as a ratio of gross returns and cost of cultivation for each crop (Maruthi Sankar *et al.*, 2012a) [13]. Ranks were assigned to each crop for performance of yield, gross returns, net returns, benefit-cost ratio, RWUE, crop seasonal rainfall and cost of cultivation and rank sums were derived for each date of sowing. Based on the procedure described by Brunner and Dette, (1992) [14], a superior crop with lowest rank sum could be identified for each date of sowing. Thus, efficient crops with optimal dates of sowing could be identified for arid Alfisols based on the study.

**Results and Discussion**

**Relationship between different parameters**

The relationships of crop seasonal rainfall with growing period of crops when sown on 5 dates of sowing were assessed and are described in [Fig-4]. A positive relationship was observed between crop seasonal rainfall and growing period of crops on all dates of sowing. The CGP had a wide range with rate of increase of 1.449 days per unit increase of crop seasonal rainfall when sown on D5, followed by 0.873 days on D4, 0.704 days on D3, 0.658 days on D2 and 0.634 days on D1. Thus, the rate of change in CGP increased from D1 to D5 with increase in crop seasonal rainfall received from sowing to harvest of crops. The CGP had maximum R<sup>2</sup> of 0.772 on D1, followed by 0.682 on D2, 0.593 on D5, 0.425 on D3 and 0.292 on D4. The relationships of groundnut equivalent yield with crop seasonal rainfall and growing period of crops when sown on 5 dates of sowing were assessed and are described in [Fig-5]. A positive relationship was observed between crop seasonal rainfall and groundnut equivalent yield of crops sown on

different dates of sowing. The groundnut equivalent yield increased with maximum rate of increase of 1.811 kg ha<sup>-1</sup> per unit increase of crop seasonal rainfall when sown on D2, followed by 1.633 kg ha<sup>-1</sup> on D1, 0.977 kg ha<sup>-1</sup> on D3, 0.700 kg ha<sup>-1</sup> on D5 and 0.543 kg ha<sup>-1</sup> on D4. The groundnut equivalent yield had maximum R<sup>2</sup> of 0.214 on D2, followed by 0.150 on D1, 0.054 on D3, 0.013 on D4 and 0.011 on D5. A positive relationship was observed between CGP and groundnut equivalent yield of crops sown on different dates of sowing. The groundnut equivalent yield increased with maximum rate of increase of 2.785 kg ha<sup>-1</sup> per unit increase of CGP when sown on D1, followed by 1.719 kg ha<sup>-1</sup> on D3, 1.406 kg ha<sup>-1</sup> on D2, 1.021 kg ha<sup>-1</sup> on D4 and 0.506 kg ha<sup>-1</sup> on D5. The groundnut equivalent yield had maximum R<sup>2</sup> of 0.227 on D1, followed by 0.195 on D3, 0.127 on D4, 0.082 on D2 and 0.022 on D5.

**Analysis of variance of yield and monetary returns of crops influenced by sowing dates**

The effects of sowing dates on groundnut equivalent yield, rainwater use efficiency, gross returns and benefit-cost ratio attained by crops were assessed in each year and also when pooled over years during 2009 to 2014. The groundnut equivalent yield (kg ha<sup>-1</sup>) was determined by considering the yield (kg ha<sup>-1</sup>) and prices of crops (Rs kg<sup>-1</sup>) for assessing superiority of crops. The analysis of variance indicated a significant difference among 5 dates of sowing, 10 crops and their interaction in influencing groundnut equivalent yield, RWUE, gross returns and benefit-cost ratio in all years and when pooled over years. The mean sum of squares and F-test values of dates of sowing and crops and their interaction in yield, RWUE, gross returns and benefit-cost ratio are described in [Table-3].

**Table-3 ANOVA of yield, RWUE, gross returns and BC ratio of crops sown on different DOS during 2009 to 2014.**

Year	Effect	DOF	Groundnut equivalent yield		RWUE		Gross returns		Benefit-cost ratio	
			MSS	F	MSS	F	MSS	F	MSS	F
2009	DOS	4	976378	100.50**	17.93	23.70**	3172757000	100.70**	16.36	110.64**
	Error (a)	8	9717		0.76		31506430		0.15	
	Crops	9	90052	9.27**	16.32	37.78**	292880400	9.28**	2.86	20.41**
	DOS x Crops	36	79871	8.23**	4.21	9.74**	259489200	8.22**	1.42	10.14**
	Error (b)	90	9710		0.43		31575200		0.14	
2010	DOS	4	2506749	75.18**	13.19	63.88**	8144409000	75.19**	38.49	90.68**
	Error (a)	8	33345		0.21		108314600		0.42	
	Crops	9	1896326	64.10**	8.85	48.55**	6161114000	64.08**	27.66	54.03**
	DOS x Crops	36	152907	5.17**	0.69	3.81**	496873000	5.17**	2.02	3.95**
	Error (b)	90	29585		0.18		96151510		0.51	
2011	DOS	4	77615	22.59**	5.96	18.88**	252550200	22.59**	2.71	39.42**
	Error (a)	8	3436		0.32		11179010		0.07	
	Crops	9	503873	157.73**	20.33	65.57**	1637179000	157.83**	11.44	164.14**
	DOS x Crops	36	62972	19.71**	5.86	18.91**	204718900	19.74**	1.44	20.61**
	Error (b)	90	3195		0.31		10372850		0.07	
2012	DOS	4	198484	12.33**	1.56	0.79	644939300	12.34**	3.02	8.57**
	Error (a)	8	16101		1.98		52254470		0.35	
	Crops	9	150493	13.57**	19.86	16.50**	488768200	13.57**	0.98	4.70**
	DOS x Crops	36	48715	4.39**	1.54	1.28	158191200	4.39**	0.46	2.19**
	Error (b)	90	11091		1.20		36027600		0.21	
2013	DOS	4	294066	69.00**	9.06	12.44**	955210800	68.81**	4.91	62.56**
	Error (a)	8	4262		0.73		13881860		0.08	
	Crops	9	177267	18.69**	3.71	4.86**	576103100	18.69**	1.54	7.76**
	DOS x Crops	36	24825	2.62**	3.43	4.50**	80673630	2.62**	0.40	1.99**
	Error (b)	90	9486		0.76		30822240		0.20	
2014	DOS	4	567854	27.81**	12.95	6.65 *	1844906000	27.78 **	10.16	21.16 **
	Error (a)	8	20422		1.948		66401280		0.48	
	Crops	9	340652	13.23**	24.89	8.48 **	1107336000	13.23 **	9.76	15.83 **
	DOS x Crops	36	67418	2.62**	3.991	1.36	219042700	2.62 **	1.26	2.04 **
	Error (b)	90	25752		2.94		83669450		0.62	
Pooled	DOS	4	516947	235.08**	2.41	7.72**	1678919000	234.02**	8.62	167.39**
	Error (a)	8	2199		0.31		7174144		0.05	
	Crops	9	263474	73.83**	5.39	24.25**	855949800	73.98**	3.87	56.68**
	DOS x Crops	36	22517	6.31**	0.40	1.79*	73127370	6.32**	0.34	4.94**
	Error (b)	90	3569		0.22		11570110		0.07	

\* and \*\* indicates significance at p < 0.05 and p < 0.01 level  
 MSS : Mean sum of squares  
 DOF : Degrees of freedom  
 DOS : Date of sowing  
 Error (a) : Error of main plots  
 Error (b) : Error of sub-plots

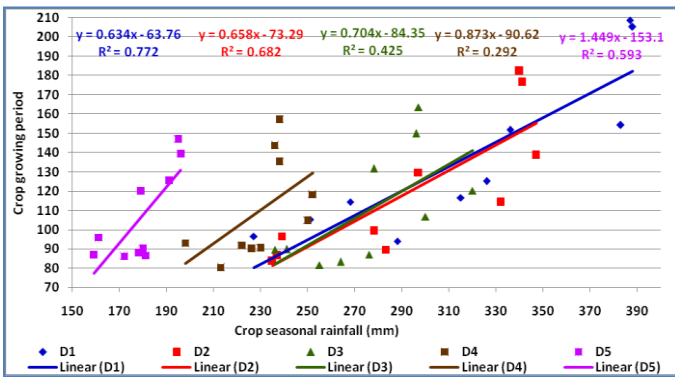
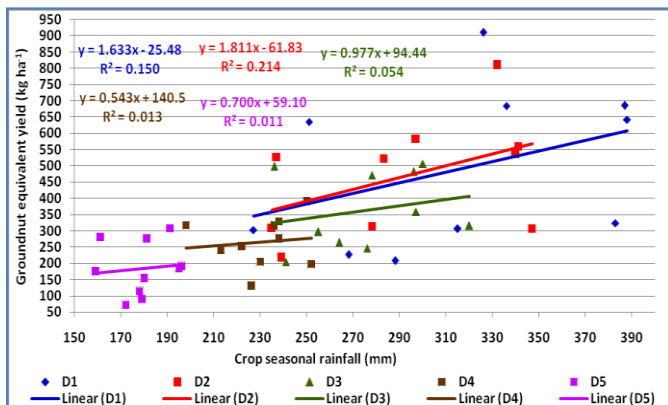


Fig-4 Relationship between crop seasonal rainfall and crop growing period of crops sown on 5 dates of sowing during 2009 to 2014



years, while maximum yield was attained when sown on D1 in 2009, 2010 and 2014; D3 in 2011; D2 in 2012 and 2013. Maximum mean yield of 492 kg ha<sup>-1</sup> was attained under D1, while minimum of 185 kg ha<sup>-1</sup> was attained when crops were sown on D5. The sowing dates influenced yield with variation in the range of 27.8% (D4) to 81.7% (D5) in 2009; 61.2% (D1) to 68.3% (D5) in 2010; 43.1% (D2) to 71.6% (D4) in 2011; 31.1% (D3) to 75.8% (D2) in 2012; 55.0% (D5) to 64.9% (D2) in 2013; and 41.2% (D1) to 58.7% (D2) in 2014. When pooled over years, the yield had a variation of 28.6% on D4 to 49.9% on D1. The crop-wise yield ranged from 203 to 471 kg ha<sup>-1</sup> in 2009; 101 to 918 kg ha<sup>-1</sup> in 2010; 98 to 721 kg ha<sup>-1</sup> in 2011; 96 to 410 kg ha<sup>-1</sup> in 2012; 41 to 351 kg ha<sup>-1</sup> in 2013; 155 to 602 kg ha<sup>-1</sup> in 2014 with variation of 24.1, 60.1, 50.4, 35.4, 55.8 and 39.1% respectively. Minimum mean yield was attained by foxtail millet in 2009, 2013 and 2014; sorghum in 2010; pearl millet in 2011; green gram in 2012, while maximum yield was attained by field bean in 2009; groundnut in 2010, 2011, 2012 and 2013; and castor in 2014. When pooled over years, groundnut attained maximum mean yield of 579 kg ha<sup>-1</sup>, while foxtail millet attained minimum yield of 170 kg ha<sup>-1</sup> with variation of 26.4% for green gram to 49.5% for pigeonpea.

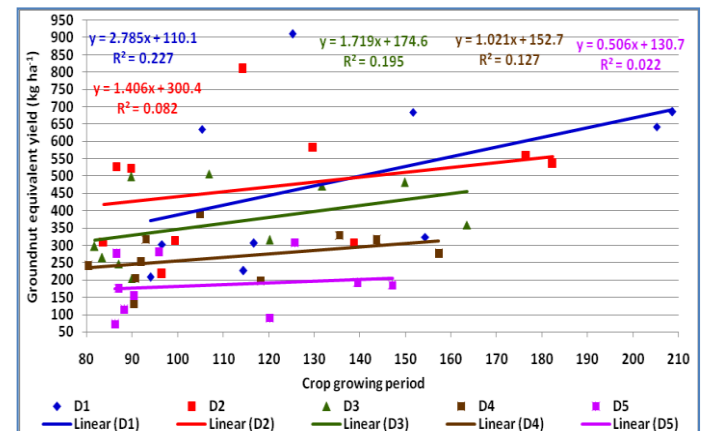


Fig-5 Relationship of groundnut equivalent yield of crops sown on different dates of sowing with crop seasonal rainfall and crop growing period

**Effect of dates of sowing on groundnut equivalent yield of crops**

The groundnut equivalent yield (kg ha<sup>-1</sup>) attained by crops when sown on different sowing dates during 2009 to 2014 are given in [Table-4]. Across the sowing dates, the yield ranged from 122 to 517 kg ha<sup>-1</sup> in 2009; 261 to 971 kg ha<sup>-1</sup> in 2010; 295 to 422 kg ha<sup>-1</sup> in 2011; 167 to 335 kg ha<sup>-1</sup> in 2012; 97 to 329 kg ha<sup>-1</sup> in 2013; and 161 to 517 kg ha<sup>-1</sup> in 2014 with variation of 24.1, 60.1, 50.4, 35.4, 55.8 and 35.8% respectively. Minimum yield was attained when crops were sown on D5 in all

**Table-4** Effect of dates of sowing on groundnut pod yield and rainwater use efficiency of crops in different years.

Crops	Groundnut pod equivalent yield (kg ha <sup>-1</sup> )								Rainwater use efficiency (kg ha <sup>-1</sup> mm <sup>-1</sup> )							
	D1	D2	D3	D4	D5	Mean	CV	D1	D2	D3	D4	D5	Mean	CV		
<b>2009</b>																
Sorghum	302	457	558	87	5	282	83.6	2.78	4.58	7.57	1.24	0.12	3.26	90.2		
Pearl millet	362	334	267	207	131	260	36.1	5.88	6.18	4.85	3.92	4.35	5.03	19.3		
Foxtail millet	251	280	247	154	83	203	40.4	3.05	3.89	3.36	2.18	2.06	2.91	26.8		
Pigeonpea	803	423	227	234	138	365	72.9	2.93	3.21	1.74	1.54	1.17	2.12	42.4		
Green gram	203	349	354	229	168	261	32.9	2.37	3.38	1.49	1.11	3.65	2.40	46.6		
Cowpea	602	580	319	272	117	378	55.1	1.13	2.57	1.96	1.02	0.87	1.51	48.1		
Field bean	677	843	274	196	367	471	58.7	4.02	2.16	0.37	0.93	0.24	1.54	102.3		
Cluster bean	232	599	360	180	88	292	67.8	3.99	3.11	0.72	1.16	1.30	2.05	68.9		
Groundnut	941	613	78	187	27	369	106.8	4.02	2.42	1.60	1.90	1.96	2.38	40.4		
Castor	796	541	102	142	92	335	95.2	0.89	2.42	2.41	1.63	2.09	1.89	34.1		
Mean	517	502	279	189	122	322	56.0	3.11	3.39	2.61	1.66	1.78	2.51	30.9		
<b>2010</b>																
Sorghum	230	113	122	89	78	101	20.4	1.02	0.53	0.51	0.46	0.43	0.59	41.4		
Pearl millet	595	592	319	267	211	347	48.7	3.91	4.40	2.43	2.24	1.55	2.91	41.3		
Foxtail millet	389	314	441	162	119	259	56.9	2.05	1.79	2.52	0.79	0.76	1.58	49.6		
Pigeonpea	1454	1046	598	255	121	505	81.7	3.12	2.10	2.41	1.95	1.15	2.15	33.3		
Green gram	292	446	389	288	190	328	34.4	1.96	1.98	1.64	1.21	1.23	1.60	23.5		
Cowpea	1477	942	1170	780	519	853	32.1	1.50	0.88	0.40	0.27	0.25	0.66	80.7		
Field bean	1344	1234	1004	593	560	848	38.6	3.24	2.98	1.79	1.03	0.87	1.98	54.9		
Clusterbean	708	394	176	108	91	192	72.5	3.65	2.82	2.71	1.90	1.11	2.44	39.8		
Groundnut	1900	1681	1064	564	363	918	64.0	3.02	2.40	1.39	0.74	0.38	1.59	69.9		
Castor	1319	978	988	649	354	742	40.8	0.77	1.25	0.93	0.76	0.53	0.85	31.3		
Mean	971	774	627	376	261	509	56.7	2.42	2.11	1.67	1.13	0.83	1.63	40.5		
<b>2011</b>																
Sorghum	419	617	738	689	159	551	48.3	3.42	6.06	7.50	8.57	2.66	5.64	45.2		
Pearl millet	196	125	112	115	38	98	41.1	3.23	2.77	1.92	2.02	0.86	2.16	42.0		

Optimal Date of Sowing of Crops for Maximizing Yield, Rainwater Use Efficiency and Monetary Returns under Arid Alfisols

Foxtail millet	251	361	33	150	6	138	117.5	3.09	5.98	0.42	1.99	0.09	2.31	102.9
Pigeonpea	365	389	290	393	402	369	14.3	3.36	4.08	4.55	1.79	3.67	3.49	30.1
Green gram	186	519	472	330	281	401	28.3	1.06	0.89	1.13	1.17	2.06	1.26	36.4
Cowpea	601	615	615	268	545	511	32.3	0.85	4.15	2.43	2.36	2.56	2.47	47.3
Field bean	339	237	277	235	307	264	13.1	3.37	1.52	3.13	4.26	3.81	3.22	32.4
Clusterbean	173	626	317	354	351	412	34.9	1.97	2.24	3.85	1.60	2.08	2.35	37.2
Groundnut	778	424	836	976	647	721	33.2	1.64	2.08	1.68	2.78	3.85	2.41	38.6
Castor	279	236	525	212	217	298	51.1	1.32	1.30	3.11	2.75	2.35	2.17	38.2
Mean	359	415	422	372	295	376	13.6	2.33	3.11	2.97	2.93	2.40	2.75	13.0
2012														
Sorghum	345	355	197	166	165	221	41.1	2.73	3.30	2.38	2.78	3.21	2.88	13.1
Pearl millet	294	285	369	238	145	259	36.1	3.71	3.93	6.33	5.82	3.76	4.71	26.8
Foxtail millet	112	165	265	149	123	176	35.4	1.07	1.70	3.40	2.64	2.41	2.24	39.9
Pigeonpea	504	350	425	186	220	295	37.8	2.19	1.77	2.92	1.77	2.45	2.22	21.9
Green gram	132	81	200	69	34	96	75.1	0.52	0.42	1.29	0.58	0.33	0.63	60.7
Cowpea	282	165	264	110	118	164	43.1	1.42	0.68	1.36	0.74	0.92	1.02	33.8
Field bean	351	246	410	118	234	252	47.7	1.06	0.87	1.97	0.79	1.82	1.30	42.4
Clusterbean	226	302	247	279	173	250	22.5	1.14	1.28	1.27	1.98	1.35	1.40	23.7
Groundnut	717	998	182	115	346	410	98.4	2.39	3.62	0.82	0.67	2.36	1.97	62.4
Castor	265	398	284	235	161	270	36.9	1.19	2.11	2.03	2.25	1.79	1.88	22.2
Mean	323	335	284	167	172	239	34.1	1.74	1.97	2.38	2.00	2.04	2.03	11.3
2013														
Sorghum	211	60	107	75	77	80	24.7	1.59	0.47	0.99	0.90	4.41	1.67	94.7
Pearl millet	77	320	194	108	39	165	73.3	0.84	3.66	2.40	1.73	3.00	2.33	47.1
Foxtail millet	110	54	13	53	42	41	47.2	2.60	1.44	0.38	1.82	1.41	1.53	52.3
Pigeonpea	312	424	143	151	58	194	82.0	2.41	3.80	1.78	1.64	0.64	2.05	56.7
Green gram	77	167	57	69	61	89	59.4	0.90	2.59	0.85	1.32	1.25	1.38	51.1
Cowpea	279	394	194	101	125	204	65.3	2.60	4.28	2.70	1.55	2.07	2.64	38.9
Field bean	414	444	141	167	159	228	63.5	2.20	2.73	1.10	1.40	1.46	1.78	37.6
Clusterbean	175	173	121	67	104	116	37.9	2.55	0.63	0.44	0.32	2.37	1.26	87.2
Groundnut	428	566	338	296	204	351	43.8	1.23	1.58	1.10	1.25	4.09	1.85	68.3
Castor	595	687	134	241	105	292	92.5	3.78	4.95	1.17	2.35	1.10	2.67	62.8
Mean	268	329	144	133	97	176	56.3	2.07	2.61	1.29	1.43	2.18	1.92	28.6
2014														
Sorghum	436	247	174	83	54	199	76.9	4.86	3.05	2.40	2.01	2.14	2.89	40.5
Pearl millet	313	233	219	295	118	236	32.6	6.03	5.09	4.19	9.48	6.21	6.20	32.3
Foxtail millet	247	126	222	116	62	155	49.9	3.89	2.12	3.18	3.00	2.47	2.93	23.3
Pigeonpea	672	586	475	438	164	467	41.3	4.15	4.01	3.73	6.05	3.71	4.33	22.6
Green gram	361	295	310	463	198	325	29.8	2.84	2.71	2.29	5.59	3.92	3.47	38.3
Cowpea	570	467	422	374	230	412	30.4	3.59	3.44	2.42	3.62	3.64	3.34	15.6
Field bean	727	359	788	587	218	536	45.2	3.14	1.72	4.34	5.66	3.45	3.66	39.9
Clusterbean	297	1042	362	531	247	496	65.2	6.63	6.99	2.07	5.50	3.92	5.02	40.6
Groundnut	694	575	538	207	102	423	60.2	2.72	2.51	2.69	1.75	1.42	2.22	26.8
Castor	852	657	792	492	217	602	42.5	5.44	4.67	6.23	6.79	4.91	5.61	15.9
Mean	517	459	430	358	161	385	35.8	4.33	3.63	3.35	4.94	3.58	3.97	16.5
Pooled														
Sorghum	324	308	316	198	90	247	41.2	2.73	3.00	3.56	2.66	2.16	2.82	18.1
Pearl millet	306	315	247	205	114	237	34.7	3.93	4.34	3.68	2.07	3.29	3.46	25.0
Foxtail millet	227	217	204	131	72	170	39.1	2.62	2.82	2.21	2.48	1.53	2.33	21.5
Pigeonpea	685	536	359	276	184	408	49.5	2.90	2.75	2.19	4.20	2.16	2.84	29.2
Green gram	208	310	297	241	155	242	26.4	1.21	2.28	1.81	1.65	1.75	1.74	22.0
Cowpea	635	527	498	317	276	451	33.4	2.84	2.97	2.53	2.10	2.10	2.51	16.2
Field bean	642	560	482	316	308	462	32.0	1.97	1.93	1.95	1.89	2.28	2.00	7.8
Clusterbean	302	523	264	253	176	304	43.1	2.30	2.75	1.43	1.86	1.89	2.05	24.4
Groundnut	910	809	506	391	281	579	46.6	2.83	2.40	1.65	1.91	2.13	2.18	20.8
Castor	684	583	471	329	191	452	43.5	3.34	3.32	2.79	2.67	2.05	2.83	18.8
Mean	492	469	364	266	185	355	36.9	2.67	2.86	2.38	2.35	2.13	2.48	11.6

In 2009, the yield ranged from 203 to 941 kg ha<sup>-1</sup> when sown on D1; compared to 280 to 843 kg ha<sup>-1</sup> on D2; 78 to 558 kg ha<sup>-1</sup> on D3; 87 to 272 kg ha<sup>-1</sup> on D4 and 5 to 367 kg ha<sup>-1</sup> on D5 with variation of 53.7, 33.5, 48.9, 27.8 and 81.7% respectively. With rainfall of 234 mm, groundnut was superior with significantly higher yield on D1 compared to field bean on D2 (285 mm), sorghum on D3 (210 mm), cowpea on D4 (201 mm) and field bean on D5 (115 mm). Field bean was superior with significantly higher yield of 471 kg ha<sup>-1</sup> with variation of 58.7%, while foxtail millet attained 203 kg ha<sup>-1</sup> with variation of 40.4% over sowing dates. Green gram gave lowest yield on D1; compared to foxtail millet on D2, groundnut on D3 and sorghum on D4 and D5. When pooled over sowing dates, field bean was superior with significantly higher groundnut equivalent yield of 471 kg ha<sup>-1</sup>, while foxtail millet gave minimum yield of 203 kg ha<sup>-1</sup> with variation of 32.9% for green gram to 106.8% for groundnut. In 2010, the yield ranged from 230 to 1900 kg ha<sup>-1</sup> when sown on D1; compared to 113 to 1681 kg ha<sup>-1</sup> on D2; 122 to 1170 kg ha<sup>-1</sup> on

D3; 89 to 780 kg ha<sup>-1</sup> on D4; and 78 to 560 kg ha<sup>-1</sup> on D5 with variation of 61.2, 62.6, 63.0, 66.1 and 68.3% respectively. Groundnut was superior with maximum yield on D1 (CRF of 588 mm) and D2 (565 mm); while cowpea was superior on D3 (552 mm) and D4 (455 mm); and field bean was superior on D5 (519 mm). Groundnut was superior with significantly higher yield on D1 and D2 compared to cowpea on D3 and D4, and field bean on D5, while sorghum gave lowest yield when sown on all sowing dates. When pooled over sowing dates, groundnut attained maximum yield of 918 kg ha<sup>-1</sup>, while sorghum attained minimum yield of 101 kg ha<sup>-1</sup> with variation of 32.1% for cowpea to 81.7% for pigeonpea. In 2011, the yield ranged from 173 to 778 kg ha<sup>-1</sup> when sown on D1; compared to 125 to 626 kg ha<sup>-1</sup> on D2; 33 to 836 kg ha<sup>-1</sup> on D3; 115 to 976 kg ha<sup>-1</sup> on D4; and 6 to 647 kg ha<sup>-1</sup> on D5 with variation of 54.8, 43.1, 62.2, 71.6 and 69.2% respectively. Groundnut was superior with significantly higher yield on D1 (CRF of 231 mm), D3 (267 mm), D4 (229 mm) and D5 (170 mm), while cluster bean was superior on D2



(172 mm). Cluster bean attained lowest yield on D1; compared to pearl millet on D2 and D4; and foxtail millet on D3 and D5. When pooled over sowing dates, groundnut was superior with significantly higher yield of 721 kg ha<sup>-1</sup>, while pearl millet attained minimum yield of 98 kg ha<sup>-1</sup>. The yield of crops over sowing dates had a variation of 13.1% for field bean to 117.5% for foxtail millet. In 2012, the yield ranged from 112 to 717 kg ha<sup>-1</sup> when sown on D1; compared to 81 to 998 kg ha<sup>-1</sup> on D2; 182 to 425 kg ha<sup>-1</sup> on D3; 69 to 279 kg ha<sup>-1</sup> on D4; and 34 to 346 kg ha<sup>-1</sup> on D5 with variation of 55.2, 75.8, 31.1, 40.5 and 48.2% respectively. Groundnut was superior with significantly higher yield on D1 (301 mm), D2 (276 mm) and D5 (146 mm); while pigeonpea was superior on D3 (237 mm) and cluster bean on D4 (161 mm). Foxtail millet gave lowest yield on D1; compared to green gram on D2, D4 and D5; and groundnut on D3. When pooled over sowing dates, groundnut was superior with significantly higher yield of 410 kg ha<sup>-1</sup>, while green gram attained minimum yield of 96 kg ha<sup>-1</sup> with variation of 22.5% for cluster bean to 98.4% for groundnut. In 2013, the yield ranged from 77 to 595 kg ha<sup>-1</sup> when sown on D1; compared to 54 to 687 kg ha<sup>-1</sup> on D2; 13 to 338 kg ha<sup>-1</sup> on D3; 53 to 296 kg ha<sup>-1</sup> on D4; and 39 to 204 kg ha<sup>-1</sup> on D5 with variation of 64.2, 64.9, 60.9, 61.3 and 55.0% respectively. Castor was superior with significantly higher yield on D1 (347 mm) and D2 (332 mm), while groundnut was superior on D3 (308 mm), D4 (237 mm) and D5 (50 mm). Pearl millet gave lowest yield on D1 and D5 compared to foxtail millet on D2, D3 and D4. When pooled over sowing dates, groundnut gave significantly higher yield of 351 kg ha<sup>-1</sup>, while foxtail millet gave minimum yield of 41 kg ha<sup>-1</sup> with variation of 24.7% for sorghum to 92.5% for castor. In 2014, the yield ranged from 247 to 852 kg ha<sup>-1</sup> when sown on D1; compared to 126 to 1042 kg ha<sup>-1</sup> on D2; 174 to 792 kg ha<sup>-1</sup> on D3; 83 to 587 kg ha<sup>-1</sup> on D4; and 54 to 247 kg ha<sup>-1</sup> on D5 with variation of 41.2, 58.7, 51.7, 49.2 and 44.6% respectively. Castor was superior with significantly higher yield on D1 (255 mm) and D3 (207 mm), compared to cluster bean on D2 (170 mm) and D5 (72 mm) and field bean on D4 (118 mm). Sorghum attained lowest yield on D3, D4 and D5, while foxtail millet attained lowest yield on D1 and D2. When pooled over sowing dates, castor gave significantly higher yield of 602 kg ha<sup>-1</sup>, while foxtail millet gave minimum yield of 155 kg ha<sup>-1</sup> with variation of 29.8% for green gram to 76.9% for sorghum. When pooled over years, the yield ranged from 208 to 910 kg ha<sup>-1</sup> when sown on D1; compared to 217 to 809 kg ha<sup>-1</sup> on D2; 204 to 506 kg ha<sup>-1</sup> on D3; 131 to 391 kg ha<sup>-1</sup> on D4; and 72 to 308 kg ha<sup>-1</sup> on D5 with variation of 49.9, 38.0, 31.7, 28.6 and 44.3% respectively. Groundnut was superior with significantly higher yield on D1, D2, D3 and D4; while field bean was superior on D5. When pooled over sowing dates, lowest yield of 170 kg ha<sup>-1</sup> was attained by foxtail millet, while highest yield of 579 kg ha<sup>-1</sup> was attained by groundnut with variation ranging from 26.4% for green gram to 49.5% for pigeonpea. The groundnut equivalent yield was significantly higher in 2010 due to better rainfall distribution, followed by 2014, 2011, 2009, 2012 and 2013. There was a large difference in the cumulative rainfall received by crops from sowing to harvest in different years. It significantly decreased from 282 to 115 mm in 2009; 606 to 482 mm in 2010; 260 to 168 mm in 2011; 299 to 146 mm in 2012; 359 to 50 mm in 2013; and 209 to 72 mm in 2014. The mean rainfall received by crops over sowing dates was significantly higher in 2009, 2010, 2012 and 2013 compared to 2011 and 2014. Due to better distribution of rainfall, the yield attained over sowing dates was maximum in 2010, followed by 2011, 2014, 2009, 2012 and 2013. Groundnut was superior with maximum yield in 2010, 2011, 2012 and 2013 compared to cluster bean in 2009 and castor in 2014; while lowest yield was attained by foxtail millet in 2009, 2013 and 2014; sorghum in 2010; pearl millet in 2011 and green gram in 2012. Maximum rainfall was available to crops when sown on D1 compared to D2, D3, D4 and D5. Accordingly, sowing made on D1 gave significantly higher yield compared to subsequent dates in all years. The groundnut equivalent yield was significantly lower when crops were sown on D5 in all years; while maximum yield was attained when sown on D2 in 2009, 2012 and 2013; D1 in 2010 and 2014 and D3 in 2011. The mean yield decreased from 492 kg ha<sup>-1</sup> attained on D1 to 469 kg ha<sup>-1</sup> on D2, 364 kg ha<sup>-1</sup> on D3, 266 kg ha<sup>-1</sup> on D4 and 185 kg ha<sup>-1</sup> on D5. The variation was maximum when sown on D5 in 2009 and 2010; D4 in 2011 and D2 in 2012, 2013 and 2014. Although, the crops sown on D1 gave significantly higher yield, maximum variation was observed when pooled over years. This indicated response of crops to early sowing compared to

delayed sowing in all years. Bacci, *et al.*, (1999) [15] observed significant effect of sowing dates and fertilizer N on millet yield in Mali. Chandrika, *et al.*, (2008) [9] observed an optimum utilization of above and below ground resources due to favorable weather parameters and maximum moisture availability in different phenophases which led to higher yield.

#### Effect of sowing dates on rainwater use efficiency of crops

The mean RWUE (kg ha<sup>-1</sup>mm<sup>-1</sup>) attained by crops on different sowing dates in each year are given in [Table-4]. It ranged from 1.51 to 5.03 kg ha<sup>-1</sup>mm<sup>-1</sup> in 2009; 0.59 to 2.91 kg ha<sup>-1</sup>mm<sup>-1</sup> in 2010; 1.26 to 5.64 kg ha<sup>-1</sup>mm<sup>-1</sup> in 2011; 0.63 to 4.71 kg ha<sup>-1</sup>mm<sup>-1</sup> in 2012; 1.26 to 2.67 in 2013; and 2.22 to 6.20 kg ha<sup>-1</sup>mm<sup>-1</sup> in 2014 with variation of 41.6, 47.0, 43.0, 56.8, 25.9 and 16.5% respectively. The lowest RWUE was attained when crops were sown on D4 in 2009; D5 in 2010; D1 in 2011 and 2012; D3 in 2013 and 2014; while highest RWUE was attained when sown on D1 in 2010; D2 in 2009, 2011, 2013; D3 in 2012 and D4 in 2014. The rainfall distribution was beneficial to crops when sown on D1 compared to subsequent dates. When pooled over years, D2 gave maximum RWUE of 2.86 kg ha<sup>-1</sup>mm<sup>-1</sup>, while D5 gave minimum of 2.13 kg ha<sup>-1</sup>mm<sup>-1</sup>. The variation of RWUE ranged from 36.2% (D2) to 83.1% (D3) in 2009; 45.9% (D1) to 59.6% (D4) in 2010; 45.5% (D1) to 73.6% (D4) in 2011; 50.4% (D5) to 79.4% (D4) in 2012; 38.4% (D4) to 59.8% (D3) in 2013; and 31.5% (D1) to 48.1% (D4) in 2014 compared to 21.8% for D5 to 32.2% for D3 when pooled over years. In 2009, the RWUE ranged from 0.89 to 5.88 kg ha<sup>-1</sup>mm<sup>-1</sup> when crops were sown on D1; compared to 2.16 to 6.18 kg ha<sup>-1</sup>mm<sup>-1</sup> on D2; 0.37 to 7.57 kg ha<sup>-1</sup>mm<sup>-1</sup> on D3; 0.93 to 3.92 kg ha<sup>-1</sup>mm<sup>-1</sup> on D4; and 0.12 to 4.35 kg ha<sup>-1</sup>mm<sup>-1</sup> on D5 with variation of 47.5, 36.2, 83.1, 53.4 and 76.9% respectively. Pearl millet was superior with significantly higher RWUE on D1, D2, D4 and D5 compared to sorghum on D3. The lowest RWUE was attained by castor on D1 compared to field bean on D2, D3 and D4 and sorghum on D5. When pooled over sowing dates, pearl millet was superior with significantly higher RWUE of 5.03 kg ha<sup>-1</sup>mm<sup>-1</sup>, compared to cowpea with minimum of 1.51 kg ha<sup>-1</sup>mm<sup>-1</sup>. The variation of RWUE over different dates of sowing ranged from 19.3% for pearl millet to 102.3% for field bean. In 2010, the RWUE ranged from 0.77 to 3.91 kg ha<sup>-1</sup>mm<sup>-1</sup> when sown on D1; 0.53 to 4.40 kg ha<sup>-1</sup>mm<sup>-1</sup> when sown on D2; 0.40 to 2.71 kg ha<sup>-1</sup>mm<sup>-1</sup> when sown on D3; 0.27 to 2.24 kg ha<sup>-1</sup>mm<sup>-1</sup> when sown on D4; and 0.25 to 1.55 kg ha<sup>-1</sup>mm<sup>-1</sup> when sown on D5 with variation of 45.9, 53.4, 50.8, 59.6 and 51.8% respectively. Pearl millet was superior with significantly higher RWUE on D1, D2, D4 and D5 compared to cluster bean on D3. The lowest RWUE was attained by castor on D1, sorghum on D2, cowpea on D3, D4 and D5. When pooled over sowing dates, pearl millet was superior with significantly higher RWUE of 2.91 kg ha<sup>-1</sup>mm<sup>-1</sup>, while sorghum had minimum of 0.59 kg ha<sup>-1</sup>mm<sup>-1</sup>. The variation of RWUE of crops over different sowing dates ranged from 23.5% for green gram to 80.7% for cowpea. In 2011, the RWUE ranged from 0.85 to 3.42 kg ha<sup>-1</sup>mm<sup>-1</sup> when sown on D1; compared to 0.89 to 6.06 kg ha<sup>-1</sup>mm<sup>-1</sup> on D2; 0.42 to 7.50 kg ha<sup>-1</sup>mm<sup>-1</sup> on D3; 1.17 to 8.57 kg ha<sup>-1</sup>mm<sup>-1</sup> on D4; and 0.09 to 3.85 kg ha<sup>-1</sup>mm<sup>-1</sup> on D5 with variation of 45.5, 60.3, 68.0, 73.6 and 51.5% respectively. Sorghum was superior with significantly higher RWUE on D1, D2, D3 and D4 compared to groundnut on D5. The lowest RWUE was attained by cowpea on D1; green gram on D2 and D4; and foxtail millet on D3 and D5. When pooled over sowing dates, sorghum attained maximum RWUE of 5.64 kg ha<sup>-1</sup>mm<sup>-1</sup>, while green gram attained minimum RWUE of 1.26 kg ha<sup>-1</sup>mm<sup>-1</sup>. The variation of RWUE over different sowing dates ranged from 30.1% for pigeonpea to 102.9% for foxtail millet. In 2012, the RWUE ranged from 0.52 to 3.71 kg ha<sup>-1</sup>mm<sup>-1</sup> when sown on D1 compared to 0.42 to 3.93 kg ha<sup>-1</sup>mm<sup>-1</sup> on D2; 0.82 to 6.33 kg ha<sup>-1</sup>mm<sup>-1</sup> on D3; 0.58 to 5.82 kg ha<sup>-1</sup>mm<sup>-1</sup> on D4 and 0.33 to 3.76 kg ha<sup>-1</sup>mm<sup>-1</sup> on D5 with variation of 56.3, 63.8, 67.4, 79.1 and 50.4% respectively. Pearl millet was superior with significantly higher RWUE on all sowing dates; while green gram attained lowest RWUE on D1, D2, D4 and D5 compared to groundnut on D3. When pooled over sowing dates, pearl millet was superior with significantly higher RWUE of 4.71 kg ha<sup>-1</sup>mm<sup>-1</sup>, while green gram attained minimum RWUE of 0.63 kg ha<sup>-1</sup>mm<sup>-1</sup>. The variation of RWUE over different sowing dates ranged from 13.1% for sorghum to 62.4% for groundnut. In 2013, the RWUE ranged from 0.84 to 3.78 kg ha<sup>-1</sup>mm<sup>-1</sup> when sown on D1 compared to 0.47 to 4.95 kg ha<sup>-1</sup>mm<sup>-1</sup> on D2; 0.38 to 2.70 kg ha<sup>-1</sup>mm<sup>-1</sup> on D3; 0.32 to 2.35 kg ha<sup>-1</sup>mm<sup>-1</sup> on D4; and 0.64 to 4.41 kg ha<sup>-1</sup>mm<sup>-1</sup> on

D5 with variation of 44.6, 59.4, 59.8, 38.4 and 58.9% respectively. Castor was superior with significantly higher RWUE on D1, D2 and D4, cowpea on D3 and sorghum on D5, while lowest RWUE was attained by pearl millet on D1, sorghum on D2, foxtail millet on D3, cluster bean on D4 and pigeonpea on D5. When pooled over sowing dates, castor was superior with significantly higher RWUE of 2.67 kg ha<sup>-1</sup>mm<sup>-1</sup>, while cluster bean attained minimum RWUE of 1.26 kg ha<sup>-1</sup>mm<sup>-1</sup>. The variation of RWUE over different sowing dates ranged from 37.6% for field bean to 94.7% for sorghum. In 2014, the RWUE ranged from 2.72 to 6.63 kg ha<sup>-1</sup>mm<sup>-1</sup> when sown on D1 compared to 1.72 to 6.99 kg ha<sup>-1</sup>mm<sup>-1</sup> on D2; 2.07 to 6.23 kg ha<sup>-1</sup>mm<sup>-1</sup> on D3; 1.75 to 9.48 kg ha<sup>-1</sup>mm<sup>-1</sup> on D4; and 1.42 to 6.21 kg ha<sup>-1</sup>mm<sup>-1</sup> on D5 with variation of 31.5, 44.1, 38.7, 48.1 and 38.3% respectively. Cluster bean was superior with significantly higher RWUE when sown on D1 and D2 compared to castor on D3 and pearl millet on D4 and D5. Groundnut attained lowest RWUE when sown on D1, D4 and D5; while field bean and cluster bean attained lowest RWUE on D2 and D3 respectively. Cowpea had lowest variation of 15.6%, while cluster bean had highest variation of 40.6% for RWUE when pooled over sowing dates. When pooled over years, the mean RWUE ranged from 1.21 to 3.93 kg ha<sup>-1</sup>mm<sup>-1</sup> when sown on D1; compared to 1.93 to 4.34 kg ha<sup>-1</sup>mm<sup>-1</sup> on D2; 1.43 to 3.68 kg ha<sup>-1</sup>mm<sup>-1</sup> on D3; 1.65 to 4.20 kg ha<sup>-1</sup>mm<sup>-1</sup> on D4 and 1.53 to 3.29 kg ha<sup>-1</sup>mm<sup>-1</sup> on D5 with variation of 27.7, 22.9, 32.2, 31.4 and 21.8% respectively. Pearl millet was superior with significantly higher RWUE when sown on D1, D2, D3 and D5, while pigeonpea was superior when sown on D4. Green gram attained lowest RWUE when sown on D1 and D4; compared to field bean on D2; cluster bean on D3 and foxtail millet on D5. Significantly lower RWUE of 1.74 kg ha<sup>-1</sup>mm<sup>-1</sup>

was attained by green gram, while significantly higher RWUE of 3.46 kg ha<sup>-1</sup>mm<sup>-1</sup> was attained by pearl millet. The RWUE of crops over sowing dates had a variation of 7.8% for field bean to 29.2% for pigeonpea. Based on pooled data over years, pearl millet gave highest RWUE of 6.20 kg ha<sup>-1</sup>mm<sup>-1</sup> compared to groundnut with lowest RWUE of 2.22 kg ha<sup>-1</sup>mm<sup>-1</sup>. However, cowpea had minimum variation of 15.6%, while cluster bean had maximum variation of 40.6% over years. The RWUE was significantly higher in 2014, followed by 2011, 2009, 2012, 2013 and 2010. Rockstrom, *et al.*, (2003) [17] observed that any rainfed crop would be superior if it utilizes the rainwater in an efficient manner under different crop growth stages. This would provide maximum rainwater use efficiency even under low and erratic rainfall situations. Sivakumar and Salaam (1999) [18] observed a significant influence of crop seasonal rainfall received in a year and fertilizer application on rainwater use efficiency of pearl millet in Niger. Sahadeva Reddy *et al.*, (2010) [19] indicated that sowing in 1<sup>st</sup> fortnight of July was most appropriate for groundnut where as both 1<sup>st</sup> and 2<sup>nd</sup> fortnights are suitable for pigeonpea and castor. In another study by Sahadeva Reddy *et al.*, (2013) [20], the authors stressed on assessing the superiority of genotypes of groundnut based on RWUE under moisture stress conditions. An optimal date of sowing would ensure better performance of any crop for best utilizing resources and providing higher yield.

**Effect of sowing dates on gross returns of crops**

The gross returns (Rs ha<sup>-1</sup>) attained by crops sown on different sowing dates during 2009 to 2014 are given in [Table-5].

**Table -5 Effect of dates of sowing on gross returns and benefit-cost ratio attained by crops in different years.**

Crops	Gross returns (Rs ha <sup>-1</sup> )							Benefit-cost ratio						
	D1	D2	D3	D4	D5	Mean	CV	D1	D2	D3	D4	D5	Mean	CV
<b>2009</b>														
Sorghum	17227	26053	31800	4973	267	16064	83.6	1.65	2.50	3.05	0.48	0.02	1.54	83.7
Pearl millet	20618	19033	15192	11780	7480	14821	36.1	1.03	0.95	0.76	0.59	0.38	0.74	35.9
Foxtail millet	14280	15960	14051	8762	4720	11555	40.5	1.19	1.33	1.17	0.73	0.39	0.96	40.7
Pigeonpea	45757	24115	12927	13335	7840	20795	72.9	3.41	1.80	0.96	0.99	0.58	1.55	73.0
Green gram	11582	19889	20164	13053	9596	14857	32.8	1.65	2.83	2.87	1.86	1.37	2.12	32.8
Cowpea	34300	33033	18217	15467	6700	21543	55.1	2.85	2.74	1.51	1.28	0.56	1.79	55.1
Field bean	38616	48067	15650	11150	20917	26880	58.7	2.25	2.81	0.91	0.65	1.22	1.57	58.8
Clusterbean	13250	34150	20533	10233	5000	16633	67.9	0.99	2.56	1.54	0.77	0.38	1.25	67.9
Groundnut	53618	34960	4427	10678	1539	21044	106.8	2.29	1.49	0.19	0.46	0.07	0.90	106.7
Castor	45383	30858	5798	8120	5238	19079	95.2	4.04	2.75	0.52	0.72	0.47	1.70	95.2
Mean	29463	28612	15876	10755	6930	18327		2.14	2.18	1.35	0.85	0.54	1.41	
<b>2010</b>														
Sorghum	13133	6427	6967	5100	4453	7216	47.9	1.26	0.61	0.67	0.49	0.43	0.69	47.9
Pearl millet	33930	33730	18175	15255	11990	22616	46.3	1.70	1.69	0.91	0.77	0.60	1.13	46.2
Foxtail millet	22153	17927	25173	9233	6767	16251	49.3	1.85	1.50	2.10	0.77	0.56	1.36	49.3
Pigeonpea	82857	59652	34067	14525	6918	39604	79.9	6.17	4.44	2.54	1.08	0.51	2.95	79.9
Green gram	16627	25440	22187	16413	10827	18299	30.9	2.37	3.62	3.16	2.34	1.54	2.60	30.9
Cowpea	84200	53733	66717	44450	29583	55737	37.5	6.99	4.46	5.54	3.69	2.45	4.63	37.5
Field bean	76650	70317	57200	33817	31900	53977	38.0	4.47	4.10	3.34	1.97	1.86	3.15	38.0
Clusterbean	40383	22467	10033	6150	5217	16850	88.1	3.03	1.69	0.76	0.46	0.39	1.26	88.1
Groundnut	108300	95817	60629	32129	20672	63509	60.4	4.63	4.10	2.59	1.37	0.88	2.71	60.4
Castor	75157	55767	56280	36983	20160	48869	42.9	6.69	4.97	5.01	3.29	1.79	4.35	42.9
Mean	55339	44128	35743	21406	14849	34293		3.92	3.12	2.66	1.62	1.10	2.48	
<b>2011</b>														
Sorghum	23880	35180	42060	39280	9040	29888	45.4	2.29	3.37	4.03	3.76	0.86	2.86	45.4
Pearl millet	11180	7140	6375	6540	2185	6684	47.8	0.56	0.36	0.32	0.33	0.11	0.34	47.6
Foxtail millet	14280	20560	1893	8567	300	9120	93.0	1.19	1.72	0.16	0.71	0.03	0.76	93.0
Pigeonpea	20802	22155	16520	22377	22913	20953	12.4	1.55	1.65	1.23	1.67	1.71	1.56	12.4
Green gram	10600	29600	26880	18800	16000	20376	38.4	1.51	4.22	3.83	2.68	2.28	2.90	38.4
Cowpea	34250	35050	35050	15250	31083	30137	28.1	2.84	2.91	2.91	1.27	2.58	2.50	28.1
Field bean	19300	13500	15800	13367	17500	15893	16.1	1.13	0.79	0.92	0.78	1.02	0.93	16.4
Clusterbean	9850	35700	18050	20150	20000	20750	45.1	0.74	2.68	1.35	1.51	1.50	1.56	45.1
Groundnut	44346	24149	47652	55632	36860	41728	28.6	1.90	1.03	2.04	2.38	1.58	1.78	28.5
Castor	15925	13475	29901	12075	12355	16746	44.8	1.42	1.20	2.66	1.08	1.10	1.49	44.7
Mean	20441	23651	24018	21204	16824	21228		1.51	1.99	1.94	1.62	1.28	1.67	
<b>2012</b>														
Sorghum	19660	20233	11233	9493	9413	14006	39.1	1.88	1.94	1.07	0.91	0.90	1.34	39.0
Pearl millet	16745	16230	21025	13545	8265	15162	31.0	0.84	0.82	1.06	0.68	0.41	0.76	31.1
Foxtail millet	6407	9393	15087	8487	7053	9285	37.1	0.54	0.78	1.26	0.71	0.59	0.77	37.0
Pigeonpea	28712	19962	24220	10605	12557	19211	39.8	2.14	1.49	1.81	0.79	0.94	1.43	39.8
Green gram	7520	4627	11427	3947	1960	5896	62.4	1.07	0.66	1.63	0.56	0.28	0.84	62.5



sowing dates had a variation of 32.9% for green gram to 106.8% for groundnut. In 2010, the gross returns ranged from Rs.13133 to Rs.108300 ha<sup>-1</sup> when sown on D1; compared to Rs.6427 to Rs.95817 ha<sup>-1</sup> on D2; Rs.6967 to Rs.66717 ha<sup>-1</sup> on D3; Rs.5100 to Rs.44450 ha<sup>-1</sup> on D4; and Rs.4453 to Rs.31900 ha<sup>-1</sup> on D5 with variation of 61.1, 62.6, 63.0, 66.1 and 68.2% respectively. Groundnut gave significantly higher gross returns on D1 and D2; compared to cowpea on D3 and D4; and field bean on D5, while sorghum gave lowest gross returns on all sowing dates. When pooled over sowing dates, groundnut gave significantly higher gross returns of Rs.63509 ha<sup>-1</sup>, compared to sorghum with minimum returns of Rs.7216 ha<sup>-1</sup>. The gross returns of crops over different sowing dates had a variation of 30.9% for green gram to 88.1% for cluster bean. In 2011, the gross returns ranged from Rs.9850 ha<sup>-1</sup> to Rs.44346 ha<sup>-1</sup> when sown on D1; compared to Rs.7140 to 35700 ha<sup>-1</sup> on D2; Rs.1893 to Rs.47652 ha<sup>-1</sup> on D3; Rs.6540 to Rs.55632 ha<sup>-1</sup> on D4; and Rs.300 to Rs.36860 ha<sup>-1</sup> on D5 with variation of 54.8, 43.1, 62.2, 71.6 and 69.2% respectively. Groundnut was superior with significantly higher gross returns on D1, D3, D4 and D5; while cluster bean was superior on D2. Cluster bean gave lowest gross returns on D1; compared to pearl millet on D2 and D4; foxtail millet on D3 and D5. When pooled over sowing dates, groundnut was superior with significantly higher returns of Rs.41728 ha<sup>-1</sup>, while pearl millet gave lowest returns of Rs.6684 ha<sup>-1</sup>. The gross returns of crops over sowing dates had a variation of 12.4% for pigeonpea to 93.0% for foxtail millet. In 2012, the gross returns ranged from Rs.6407 to Rs.40850 ha<sup>-1</sup> when crops were sown on D1; compared to Rs.4627 to Rs.56905 ha<sup>-1</sup> on D2; Rs.10374 to Rs.24220 ha<sup>-1</sup> on D3; Rs.3947 to Rs.15900 ha<sup>-1</sup> on D4; and Rs.1960 to Rs.19690 ha<sup>-1</sup> on D5 with variation of 55.2, 75.8, 31.0, 40.4 and 48.0% respectively. Groundnut was superior with significantly higher gross returns on D1, D2 and D5 compared to pigeonpea on D3 and cluster bean on D4. Foxtail millet gave lowest gross returns on D1 compared to green gram on D2, D4 and D5 and groundnut on D3. When pooled over sowing dates, groundnut was superior with significantly higher returns of Rs.26871 ha<sup>-1</sup>, while green gram attained minimum returns of Rs.5896 ha<sup>-1</sup>. The gross returns of crops over sowing dates had a variation of 20.4% for cluster bean to 79.7% for groundnut. In 2013, the gross returns ranged from Rs.4373 to Rs.33915 ha<sup>-1</sup> when sown on D1 compared to Rs.3107 to Rs.39142 ha<sup>-1</sup> on D2; Rs.720 to Rs.19285 ha<sup>-1</sup> on D3; Rs.3033 to Rs.16853 ha<sup>-1</sup> on D4; and Rs.2250 to Rs.11647 ha<sup>-1</sup> on D5 with variation of 64.2, 64.8, 61.0, 61.2 and 55.1% respectively. Castor was superior with significantly higher returns on D1 and D2, while groundnut was superior on D3, D4 and D5. Green gram gave lowest returns on D1 compared to foxtail millet on D2, D3 and D4 and pearl millet on D5. When pooled over sowing dates, groundnut was superior with significantly higher returns of Rs.20885 ha<sup>-1</sup>, while foxtail millet gave lowest returns of Rs.3104 ha<sup>-1</sup>. The gross returns of crops over different sowing dates had a variation of 36.2% for cluster bean to 76.6% for castor. In 2014, the gross returns ranged from Rs.14080 to Rs.48568 ha<sup>-1</sup> when sown on D1 compared to Rs.7200 to Rs.59400 ha<sup>-1</sup> on D2; Rs.9940 to Rs.45150 ha<sup>-1</sup> on D3; Rs.4753 to Rs.33433 ha<sup>-1</sup> on D4 and Rs.3087 to Rs.14100 ha<sup>-1</sup> on D5 with variation of 41.2, 58.7, 51.7, 49.1 and 44.6% respectively. Castor was superior with significantly higher returns on D1 and D3; while cluster bean was superior on D2 and D5; and field bean was superior on D4. Foxtail millet gave lowest returns on D1 and D2; while sorghum gave lowest returns on D3, D4 and D5. When pooled over sowing dates, castor was superior with significantly higher returns of Rs.34312 ha<sup>-1</sup>, while foxtail millet gave lowest returns of Rs.8823 ha<sup>-1</sup>. The gross returns of crops over sowing dates had a variation of 29.8% for green gram to 76.8% for sorghum. There was a decrease in returns as sowing date was delayed from D1 to D5. When pooled over years, the mean gross returns ranged from Rs.11875 to 51848 ha<sup>-1</sup> when sown on D1 compared to lower range of Rs.12358 to Rs.46138 ha<sup>-1</sup> on D2; Rs.11600 to Rs.28839 ha<sup>-1</sup> on D3; Rs.7447 to Rs.22268 ha<sup>-1</sup> on D4; and Rs.4129 to 17531 ha<sup>-1</sup> on D5 with variation of 49.8, 38.1, 31.7, 28.6 and 44.4% respectively. Groundnut attained significantly higher returns when sown on D1, D2, D3 and D4, compared to field bean on D5. When pooled over sowing dates, foxtail millet gave significantly lower returns of Rs.9690 ha<sup>-1</sup>, while groundnut gave maximum returns of Rs.33026 ha<sup>-1</sup>. Green gram had lowest variation of 26.3%, while pigeonpea had highest variation of 49.5% when pooled over sowing dates during 2009 to 2014.

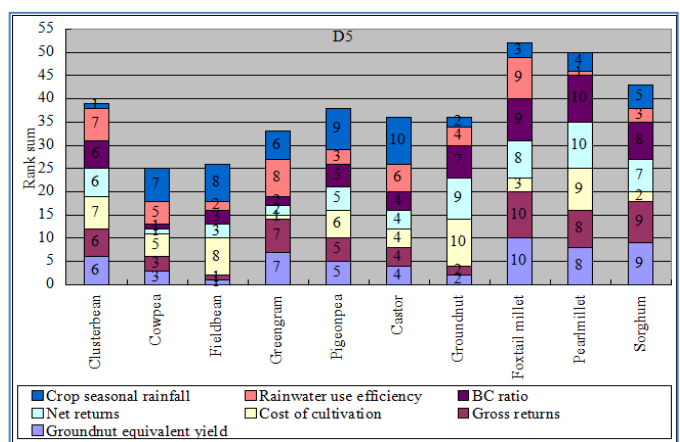
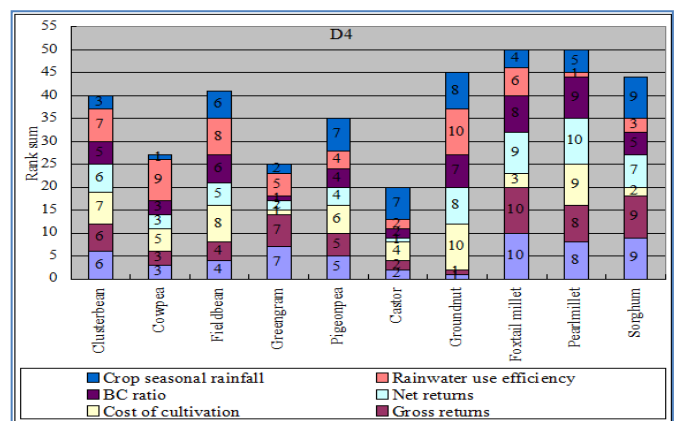
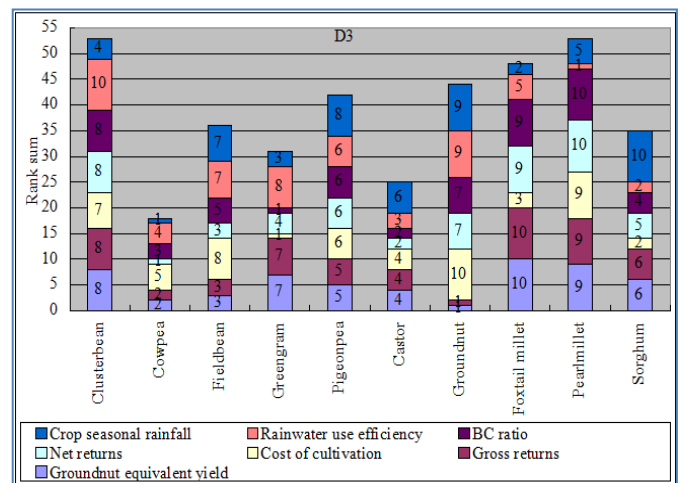
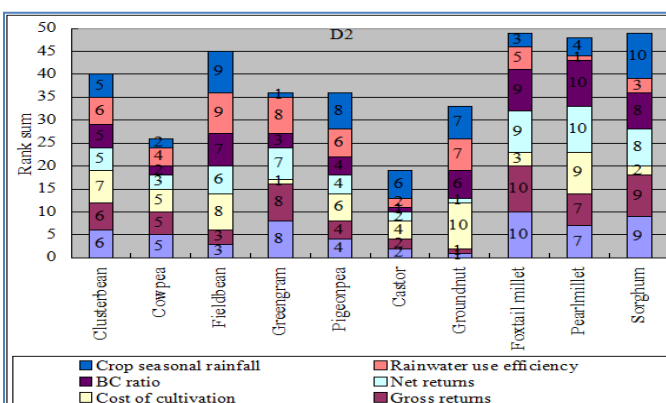
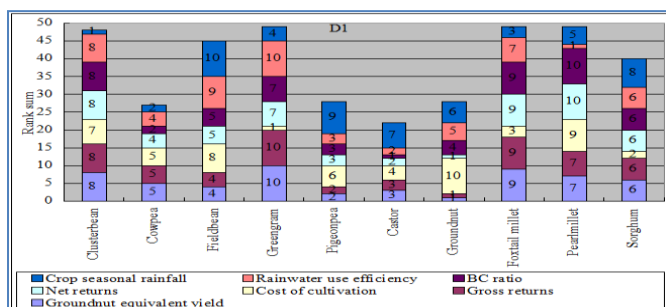
### Effect of sowing dates on benefit-cost ratio of crops

The benefit-cost ratios attained by crops on different sowing dates are given in [Table-5]. The BC ratio ranged from 0.54 (D5) to 2.18 (D2) in 2009; 1.10 (D5) to 3.92 (D1) in 2010; 1.28 (D5) to 1.99 (D2) in 2011; 0.69 (D5) to 1.30 (D1 and D2) in 2012; 0.40 (D5) to 1.33 (D2) in 2013; and 0.75 (D5) to 2.26 (D1) in 2014. In 2009, it ranged from 1.03 to 4.04 when sown on D1; compared to 0.95 to 2.83 on D2; 0.19 to 3.05 on D3; 0.46 to 1.86 on D4; and 0.02 to 1.37 on D5 with variation of 48.6, 32.7, 70.0, 50.5 and 80.5% respectively. Castor was superior with significantly higher BC ratio on D1; compared to green gram on D2, D4 and D5 and sorghum on D3. Pearl millet gave lowest BC ratio on D1 and D2; compared to groundnut on D3 and D4; and sorghum on D5. When pooled over sowing dates, green gram was superior with significantly higher BC ratio of 2.12, while pearl millet was uneconomical with lowest BC ratio of 0.74. The BC ratio of crops over different sowing dates had a variation of 32.8% for green gram to 106.7% for groundnut. In 2010, the BC ratio ranged from 1.26 to 6.99 when sown on D1; compared to 0.61 to 4.97 on D2; 0.67 to 5.54 on D3; 0.46 to 3.69 on D4; and 0.39 to 2.45 on D5 with variation of 55.5, 50.3, 63.2, 71.6 and 67.4% respectively. Cowpea was superior with significantly higher BC ratio on D1, D3, D4 and D5; compared to castor on D2. Sorghum gave lowest BC ratio on D1, D2 and D3; compared to cluster bean on D4 and D5. When pooled over sowing dates, cowpea was superior with significantly higher BC ratio of 4.63, while sorghum was uneconomical with minimum BC ratio of 0.69. The BC ratio of crops over different sowing dates had a variation of 30.9% for green gram to 88.1% for cluster bean. In 2011, the BC ratio ranged from 0.56 to 2.84 when sown on D1; compared to 0.36 to 4.22 on D2; 0.16 to 3.83 on D3; 0.33 to 3.76 on D4; and 0.03 to 2.58 on D5 with variation of 45.6, 62.6, 70.9, 65.0 and 65.1% respectively. Cowpea was superior with significantly higher BC ratio on D1 and D5; while green gram was superior on D2 and D3; and sorghum was superior on D4. Pearl millet gave lowest BC ratio on D1, D2 and D4; while foxtail millet gave lowest BC ratio on D3 and D5. When pooled over sowing dates, green gram was superior with significantly higher BC ratio of 2.90, while pearl millet was uneconomical with minimum BC ratio of 0.34. The BC ratio of crops over sowing dates had a variation of 12.4% for pigeonpea to 93.0% for foxtail millet. In 2012, the BC ratio ranged from 0.54 to 2.14 when sown on D1; compared to 0.66 to 2.43 on D2; 0.44 to 1.81 on D3; 0.28 to 1.19 on D4; and 0.28 to 0.94 on D5 with variation of 38.1, 48.9, 30.2, 42.6 and 31.9% respectively. Pigeonpea was superior with significantly higher BC ratio on D1, D3 and D5, compared to groundnut on D2 and cluster bean on D5. Foxtail millet gave lowest BC ratio on D1 compared to green gram on D2 and D5; and groundnut on D3 and D4. When pooled over sowing dates, pigeonpea gave significantly higher BC ratio of 1.43, while pearl millet was uneconomical with BC ratio of 0.76. The BC ratio of crops over different sowing dates had a variation of 20.4% for cluster bean to 79.7% for groundnut. In 2013, the BC ratio ranged from 0.34 to 2.27 when sown on D1 compared to 0.33 to 2.78 on D2; 0.09 to 0.86 on D3; 0.29 to 1.04 on D4; and 0.16 to 0.59 on D5 with variation of 52.6, 56.8, 42.1, 42.6 and 34.5% respectively. Castor was superior with significantly higher BC ratio on D1, D2 and D4 compared to pearl millet on D3 and field bean on D5. Pearl millet gave lowest BC ratio on D1 and D5 compared to sorghum on D2, foxtail millet on D3 and cluster bean on D4. When pooled over sowing dates, castor was superior with significantly higher BC ratio of 1.41, while foxtail millet was uneconomical with BC ratio of 0.36. The BC ratio of crops over sowing dates had a variation of 36.2% for cluster bean to 74.7% for castor. In 2014, the BC ratio ranged from 0.90 to 4.33 when sown on D1 compared to 0.60 to 4.46 on D2; 0.62 to 4.02 on D3; 0.46 to 3.76 on D4; and 0.25 to 1.61 on D5 with variation of 45.8, 60.8, 53.8, 65.3 and 61.3% respectively. Castor was superior with significantly higher BC ratio on D1 and D3 compared to cluster bean on D2 and green gram on D4 and D5. Pearl millet had lowest BC ratio on D1 and D3 compared to sorghum on D4; foxtail millet on D2 and groundnut on D5. When pooled over sowing dates, castor was superior with significantly higher BC ratio of 3.06, while pearl millet was uneconomical with BC ratio of 0.67. The BC ratio of crops over sowing dates had a variation of 29.8% for green gram to 76.4% for sorghum. It decreased as the sowing date shifted from D1 to D5. When pooled over years, the mean benefit-cost ratio ranged from 0.90 to 3.35 when sown on D1 compared to 0.96 to 2.84 on D2; 0.76 to 2.39 on D3; 0.61 to 1.93 on D4; and 0.33 to 1.30 on D5 with variation

of 41.3, 30.8, 37.3, 35.8 and 43.5% respectively. Castor was superior with significantly higher BC ratio when sown on D1 and D2 compared to green gram on D3 and D4; and cowpea on D5. When pooled over sowing dates, significantly lower BC ratio of 0.71 was attained by pearl millet, while maximum BC ratio of 2.23 was attained by castor. The BC ratio of crops over different sowing dates had a variation of 26.0% for green gram to 49.7% for pigeonpea. The pooled ANOVA of yield indicated the superiority of groundnut with maximum yield on D1, D2, D3 and D4, while field bean was superior on D5. When pooled over DOS, foxtail millet gave significantly lower groundnut equivalent yield of 170 kg ha<sup>-1</sup> compared to highest yield of 579 kg ha<sup>-1</sup> by groundnut. Green gram had minimum variation of 26.4%, while pigeonpea had maximum variation of 49.5%. The pooled ANOVA of RWUE indicated the superiority of pearl millet with significantly higher RWUE when sown on D1, D2, D3 and D5, while pigeonpea was superior on D4. Field bean had minimum variation of 7.8% compared to pigeonpea with maximum variation of 29.2%. Raes *et al.*, (2004) [20] evaluated planting dates of crops for maximizing yield based on weather parameters and identified superior planting dates for crops grown under different soils in Zimbabwe. The pooled ANOVA of gross returns indicated that foxtail millet was inferior with lowest gross returns of Rs.9690 ha<sup>-1</sup> compared to significantly higher gross returns of Rs.33026 ha<sup>-1</sup> attained by groundnut. The gross returns had a variation of 26.3% for green gram to 49.5% for pigeonpea. The pooled ANOVA of benefit-cost ratio indicated that castor was superior with significantly higher BC ratio on D1 and D2 compared to green gram on D3 and D4 and cowpea on D5. When pooled over sowing dates, pearl millet was unprofitable with lowest BC ratio of 0.71 compared to significantly higher BC ratio of 2.23 by castor. Green gram had minimum variation of 26.0%, while pigeonpea had maximum variation of 49.7%. Thakur *et al.*, (2010) [21] observed superiority of soybean and maize for yield and monetary returns when crops were sown under normal onset of monsoon than delayed condition. This was due to low soil moisture availability under delayed condition which drastically affected the yield. Huang *et al.*, (2006) [22] discussed the strategies for improving maize yield with improved RWUE. Suitable varieties could be identified for enhancing RWUE under limited rainfall condition. Nema *et al.*, (2008) [23] observed a decreasing pearl millet yield with lower soil moisture when sowing was delayed due to delay in the onset of monsoon.

**Ranking of crops for superiority on different dates of sowing**

The rank sum of crops for groundnut equivalent yield, RWUE, gross returns and benefit-cost ratio on each date of sowing are depicted in [Fig-6].



**Fig-6 Superiority of crops based on ranks assigned to different parameters.**

The rank sums indicated that castor was superior on D1, D2 and D4, while cowpea was superior on D3 and D5 with lowest rank sum compared to other crops. When sown on D1, castor was superior with rank sum of 22; while cowpea was the 2<sup>nd</sup> best with rank sum of 26; and pigeonpea and groundnut were the 3<sup>rd</sup> best crops with rank sum of 28. When sown on D1 and D2, groundnut was superior for pod yield and gross returns, while castor was superior for benefit-cost ratio and pearl millet was superior for RWUE. When sown on D3 and D4, groundnut was superior for pod yield and gross returns; while green gram was superior for benefit-cost ratio and pearl millet was superior for RWUE. When crops were sown on D5, field bean was superior for groundnut equivalent yield and gross returns; while cowpea was superior for benefit-cost ratio and pearl millet was superior for rainwater use efficiency. The rank analysis indicated that groundnut was superior for pod yield and gross returns when sown on D1, D2, D3 and D4, while field bean was superior on D5. Castor was superior for benefit-cost ratio on D1 and D2, compared to green gram on D3 and D4 and cowpea on D5.

Pearl millet was superior for RWUE on all 5 sowing dates. Halekoh and Kristensen (2008) [24] evaluated the effects of treatments based on ranking procedure and identified a superior treatment for sustaining yield of potato. Based on gross returns and benefit-cost ratio from pooled data over years, pearl millet was unprofitable on all dates of sowing. Groundnut and foxtail millet were unprofitable on D4 and D5; while castor, cluster bean, sorghum and pigeonpea were unprofitable on D5. Only green gram, cowpea and field bean were profitable on all sowing dates. Although groundnut on D1, D2, D3 and D4 and field bean on D5 were efficient with maximum pod yield and gross returns; castor on D1 and D2, green gram on D3 and D4 and cowpea on D5 were efficient with maximum BC ratio. Green gram, pearl millet, field bean, cluster bean, sorghum and foxtail millet were inefficient due to high rank sum for different parameters studied. Castor, cowpea, groundnut and pigeonpea were superior for different parameters and attained lower rank sum based on the study. Castor attained 1<sup>st</sup> rank on D1, D2 and D4, 2<sup>nd</sup> rank on D3 and 4<sup>th</sup> rank on D5. Cowpea attained 1<sup>st</sup> rank on D3 and D5, 2<sup>nd</sup> rank on D1 and D2 and 3<sup>rd</sup> rank on D4. Groundnut attained 3<sup>rd</sup> rank on D1 and D2, 4<sup>th</sup> rank on D5, 7<sup>th</sup> rank on D3 and 8<sup>th</sup> rank on D4. Pigeonpea attained 3<sup>rd</sup> rank on D1, 4<sup>th</sup> rank on D2 and D4, 5<sup>th</sup> rank on D5 and 6<sup>th</sup> rank on D3. Although green gram incurred lowest cost of cultivation on all dates of sowing, it attained 7<sup>th</sup> rank on D1, 4<sup>th</sup> rank on D2, 3<sup>rd</sup> rank on D3, 2<sup>nd</sup> rank on D4 and 3<sup>rd</sup> rank on D5. Similarly, pearl millet attained highest RWUE on all dates of sowing, but attained 7<sup>th</sup> rank on D1 and D2, 9<sup>th</sup> rank on D3 and D4, and 8<sup>th</sup> rank on D5. Based on the study, castor and cowpea on D1 and D2, cowpea and castor on D3, castor and green gram on D4, cowpea and field bean on D5 were most efficient on respective dates of sowing. Although groundnut has highest area under cultivation in Anantapur district, our study indicated that the crop is efficient only for attaining higher yield and gross returns but would provide a significantly lower benefit-cost ratio and rainwater use efficiency compared to other crops. Turner, (2004) [25] suggested different agronomic options for enhancing rainwater use efficiency when crops were grown under erratic rainfall condition, apart from maximizing productivity and profitability of crops. Sanjay Sharma, *et al.*, (2009) [26] found that soybean had a maximum sustainability for yield, RWUE and profitability under varying quantities of rainfall received in a semi-arid Vertisol. The results based on our study are in convergence with the sustainability of different crops observed by Padmani, *et al.*, (2009) [7] under semi-arid Vertisols. Anil Sharma, *et al.*, (2013) [27] assessed the superiority of maize and black gram based on rank analysis of fertilizer treatments for sustaining yield, monetary returns and rainwater use efficiency under dry sub-humid Inceptisols. Behera, *et al.*, (2012) [28] found superiority of rice and pigeonpea with a combination of organic and inorganic fertilizers for attaining maximum RWUE and monetary returns under moist sub-humid Alfisols. The efficient performance of crops when sown early with onset of monsoon could be attributed to favourable weather in terms of rainfall distribution, sunshine hours and optimum temperature at reproductive and maturity stages of crops as well as higher rainwater use efficiency. The late sown crops experienced either prolonged dry spells at either flowering or maturity stage of crops or terminal drought which resulted with drastic reduction in yields. In a similar study by Soler, *et al.*, (2008) [29], the authors have optimized the sowing dates for attaining maximum and stable productivity of pearl millet under two different environments with variation in rainfall. Vittal, *et al.*, (2002 and 2003a) [30,31] reported that timely sowing of crops resulted in harvesting good and moderate yields, whereas delayed sowing of crops resulted in low yields and inefficient use of resources. Maruthi Sankar, *et al.*, (2012b) [4] observed that efficient tillage, apart from optimum date of sowing of pearl millet would provide sustainable yield and monetary returns under low and erratic rainfall conditions. Padmani, *et al.*, (2009) [7] and Sukadia and Dhoble (1990) [32] reported that groundnut was superior with maximum monetary returns attained due to better price, apart from a higher yield over wide range of sowing dates under semi-arid Vertisols. Such yield advantage of groundnut compared to other crops was also reported by Bhange, (1985) [33] and Dhoble, *et al.*, (1987) [34]. Based on our study, castor and cowpea were more profitable than groundnut due to lower cost of cultivation and higher benefit-cost ratio attained on different sowing dates. The ranks assigned to crops on different sowing dates have also indicated the superiority of castor and cowpea for different

parameters. We recommend these two crops as most efficient alternative crops to groundnut for attaining maximum productivity, rainwater use efficiency and monetary returns under arid Alfisols.

### Conclusions

Based on field experiments with 10 crops on 5 dates of sowing conducted during *kharif* 2009 to 2014 under arid Alfisols, efficient crops and sowing dates were identified for attaining sustainable groundnut equivalent yield, rainwater use efficiency, gross returns and benefit-cost ratio. The differences in performance of crops sown on 5 sowing dates were assessed in each year and also when pooled over years. The groundnut equivalent yield attained by crops significantly decreased from D1 to D5 in different years. Similarly, the crops attained significantly lower yields due to erratic rainfall condition occurred in different years. Based on ranks assigned to crops for different parameters, castor was superior when sown on D1, D2 and D4, while cowpea was superior on D3 and D5. Although groundnut was superior for pod yield and gross returns on D1, D2, D3 and D4; castor was superior for benefit-cost ratio on D1 and D2. Cowpea was superior for benefit-cost ratio on D5, while green gram incurred minimum cost of cultivation on all sowing dates and attained maximum benefit-cost ratio on D3 and D4. Cluster bean had low crop seasonal rainfall when sown on D1 and D5, while cowpea had low crop seasonal rainfall when sown on D3 and D4. Pearl millet was superior with maximum RWUE on all sowing dates. Field bean was superior for groundnut equivalent yield and gross returns when sown on D5. Castor attained 1<sup>st</sup> rank on D1, D2 and D4, 2<sup>nd</sup> rank on D3 and 4<sup>th</sup> rank on D5; while cowpea attained 1<sup>st</sup> rank on D3 and D5, 2<sup>nd</sup> rank on D1 and D2 and 3<sup>rd</sup> rank on D4. Castor and cowpea were superior on D1, D2 and D3 compared to castor and green gram on D4; cowpea and field bean on D5. We recommend these crops for attaining maximum groundnut equivalent yield, RWUE, gross returns and benefit-cost ratio under arid Alfisols.

**Application of research:** For drought management in rainfed areas selection of suitable crops and time of sowing is the key factor for obtaining higher productivity. Selection of suitable crops in case of delayed monsoon will be very useful to the farming community.

**Research Category:** Crop growing period, Groundnut equivalent yield, Rainwater use efficiency

**Abbreviations:** CRS: Crop Seasonal Rainfall, DOS :Date of Sowing, DOH :Date of Harvesting, RWUE: Rain Water Use Efficiency, BC Ratio: Benefit Cost Ratio

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**\*Research Guide or Chairperson of research: Dr B. Sahadeva Reddy**

**University:** Acharya N. G. Ranga Agricultural University, Lam, Guntur, 522034, Andhra Pradesh

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**Conflict of Interest:** None declared

**Ethical approval:** This article does not contain any studies with human participants or animals performed by any of the authors.

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