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Effect of sowing direction and crop geometry on water use efficiency and productivity of Indian mustard (*Brassica juncea*. L.) in semi arid region of India

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Abstract

Indian mustard [*Brassica juncea* (L.) Czern & Coss.] is an important oilseed crop for the rainfed, semi-arid region of north-western plains of India. The best direction of sowing with respect to yield is still not clear. Therefore, two Indian mustard varieties differing in their phenotypes (erect and spreading type) were grown in two sowing directions [North-South (NS) and East-West (EW)] along with broadcast to study the effect of direction of sowing, and planting geometry on the actual evapotranspiration (AET), water use efficiency (WUE), biomass production, and yield. Accumulated AET was studied to be higher in the EW direction than in NS sown plots. Direction wise NS sown plots showed higher WUE, and better AET-yield production function (higher coefficient of determination) than the EW sown plots. EW sown plots produced the highest seed yield followed by broadcast sown, and NS sown plots, and proved to be the best in terms of WUE, biomass production and seed yield.

Keywords: *Crop phenotype, direction of sowing, planting geometry, water use efficiency*

Introduction

Indian mustard is an important oilseed crop of northern and north western part of India. It is grown as rainfed crop in the north Indian plains. There are many opinions about the best direction of sowing of Indian mustard with regard to the high seed yield. No consensus has been reached yet with definite scientific exploration. Jha *et al.* (2012) has studied the effect of direction of sowing, and crop phenotype on light interception efficiency, and seed yield of Indian mustard. On the contrary, water use efficiency (WUE) is more important for oilseed productivity for a water limited or rainfed region. Therefore, this present study has been done as a complementary study of the study of Jha *et al* (2012). The present study addressed this important issue of the effect of sowing direction on Indian mustard seed yield with respect to water use efficiency (WUE), and actual evapotranspiration (AET). WUE and AET addressed water as the major limiting factor of this rainfed zone. It is well established fact that when water supply is limiting there is a linear relationship between crop yield or biomass and the amount of water used for evaporanspiration (DeWitt, 1958; Viets, 1962). The relationship between yield and estimated evapotranspiration for well watered soybean crop was studied by Purcell *et al* (2006) and they reported that yield is not linearly related to seasonal transpiration over entire range of evapotranspiration values but instead reaches an asymptote at high values. The direction of sowing and the crop phenotype affect the yield of Indian mustard crop. The changes in biomass production of Indian mustard in different directions of sowing are due to the changes of actual evapotranspiration (AET), water use efficiency (WUE), and radiation interception differently in different direction of sowing. Jha *et al.* (2012) studied the impact of sowing direction of the Indian mustard on the interception of the solar radiation, but the impact of water use efficiency is required to investigate in parallel. Jin *et al*. (1999) reported that excessive amount of water supply led to decrease of crop WUE, and that effective deficit irrigation may result in higher production and WUE. Contrarily, Olesen *et al*. (2000) reported that the effect of irrigation on wheat yield was almost solely due to increased transpiration, while WUE and harvest index remained unaffected. Sun et al.(2006) studied the effect of irrigation on water balance, yield and WUE of winter wheat in the North China Plain and reported that the maximum grain yield was attained at an optimal irrigation; the irrigation requirement of winter wheat increases as with soil evaporation, but the excessive amounts of irrigation triggered growth of non-functional tillers which consumed nutrients with no function increase in grain yield. The sowing direction and crop phenotype *i.e.* planting geometry exerts influence on the AET, WUE as the crop micrometeorological condition changes manifesting the variation in terms of photosynthate production. Indian mustard crop is an important oilseed crop in the north Indian plains has been least investigated so far in this aspect. Various researchers have reported that Indian mustard seed yield is more in East-West (EW) direction of sowing than that in North-South (NS) sowing direction while the approaches of such studies were focused mainly on agronomic parameters only. In this paper the problem has been studied with taking a peer view on agro-meteorological and physiological parameters. Two different varieties differing in their phenotypic characters (erect type and spreading type) were taken for study, and grown in two different directions of sowing NS and EW (The whole block was tilted to the True NS direction of the earth after measuring the local magnetic declination). The broadcast plots were also taken along with NS, and EW directional sowings as another treatment keeping in view the magnitude of farmer's practicing the broadcast method of sowing over India for comparative study.

Materials and Methods

The present study was conducted in the experimental farm (MB-4C) of Indian Agricultural Research Institute located at $28^0 35'$ N latitude, $77^0 12'$E longitude and at an altitude of 228.16 m above mean sea level. Two cultivars of *Brassica juncea viz*; Pusa Agrani (erect type, medium height and early maturing variety), and Pusa Jagannath (bushy type, broadleaved and late maturing variety) were grown during the *rabi* season of 2004-05, following the recommended agronomic practices with one irrigation (6 cm) at pre-flowering stage. These cultivars differed in their maturity periods, growth habits, and phenotypic characters. The experiment was laid out in a randomized block design with three replications, size of each plot being 5m x 5m. The whole block was titled to 8^0 W to make the plots directed towards the true North of the Earth measuring the magnetic declination of the location with a compass. The plot design has been shown in Appendix-I. Sowing was done with hand drill, maintaining a row to row distance of 45 cm, and plant to plant distance of 15 cm. A seed rate of 5 kg/ ha was used for Pusa Agrani and 7 kg/ha for Pusa Jagannath. The seeds were sown in the rows directed towards North-South for N–S sown plots and in the rows directed towards East-West for E–W sown plots. Seeds were simply broadcast for the broadcast plots in the design. Recommended standard fertilizer doses, and crop protection measures were taken during the growing period of the crop. For determining the leaf area index, three plants were randomly selected in each plot, and cut at ground level. Each sampling was done at 7-10 days interval. The green leaf portions were separated, and the area of the leaves was measured using leaf area meter (LICOR-100). LAI was derived by using following formula :

$$LAI = [\{\text{Measured leaf area per plant } (cm^2)\} / \{100 \times 100\ (cm^2)\}] \times \text{Number of plants}$$

The samples collected for determination of leaf area index were used for assessing the above ground biomass production. For this purpose these samples were oven dried at 70^oC for more than 48 hours as recommended. To obtain the seed yield, plant samples from $10m^2$ area were harvested from the central four rows (2m x 5m) for the directionally sown plots, and randomly from the broadcast plot.

Seed yield was then recorded and converted in per m^2 on the basis of dividing by 10. Harvest index (H.I.) was calculated using the following relation :

$$\text{H.I. (\%)} = [\{\text{Seed yield (g m}^{-2}) / \text{Total biological yield (g m}^{-2})\} \times 100]$$

The soil moisture in three layers of profile (0-0.15 m, 0.15-0.30 m and 0.30-0.60 m) was estimated by gravimetric method. For this, the soil samples were collected using a screw auger at 10 days interval during the crop growth period.

Reference crop evapotranspiration (ET_O) was computed using Penman-Monteith method (Allen *et al*., 1998) on daily basis. The required meteorological data for this computation were taken from the meteorological station adjoining the experiment site. The maximum evapotranspiration (ET_{max}) for each day was determined by multiplying reference crop evapotranspiration with the crop coefficient for the corresponding day. The crop coefficients for the Indian mustard crop for the crop duration were taken from the values given by Ullah *et al*. (2001). Daily actual evapotranspiration (AET) was estimated by soil moisture balance (Lhomme and Katerji, 1991) for each plot, and daily basis. In this regard, simple bucket model concept was used. The crop water use efficiency (WUE) in (g/m^2/mm of water) for biomass production was computed by using the following formula :

$$\text{WUE} = \{\text{Total above ground biomass (g)}\} / \{\text{Accumulated AET (mm)}\}$$

Results and Discussions

Jha *et al*. (2012) studied the impact of sowing direction of the Indian mustard on the interception of the solar radiation, but the impact of water use efficiency is required to investigate in parallel to understand the relative importance of water versus light as a factor of crop production vis-à-vis crop geometry. There was an exponential increase in LAI from emergence to maximum LAI stage in both the varieties. The maximum LAI of this variety was found to reach on 80 DAS, which coincided with the pod formation stage in variety Pusa Agrani. There was no marked difference among the LAI observed for North-South sown plots, East-West sown plots or broadcast plots, though broadcast had a little higher LAI values than others in this variety (Fig 1.). The maximum LAI reached on 86 DAS, which coincided with the pod formation stage of this crop in variety Pusa Jagannath. The LAI of this variety in North-South sown plots, and East-West sown plots did not differ much except between 80-94 DAS when the LAI of East-West sown plots was found to be higher than that of the North-South sown plots due to higher growth rate (Fig 2.). The variation of above ground biomass in North-South, East-West, and broadcast plots for two varieties Pusa Agrani and Pusa Jagannath are presented in Figs.3 and 4. Pusa Agrani variety attained its peak biomass at 108 DAS whereas Pusa Jagannath attained its maximum biomass at 124 DAS. This

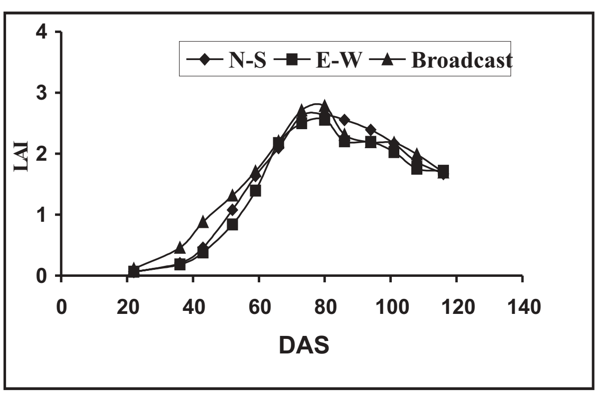

Fig. 1. Variation of LAI in Pusa Agrani

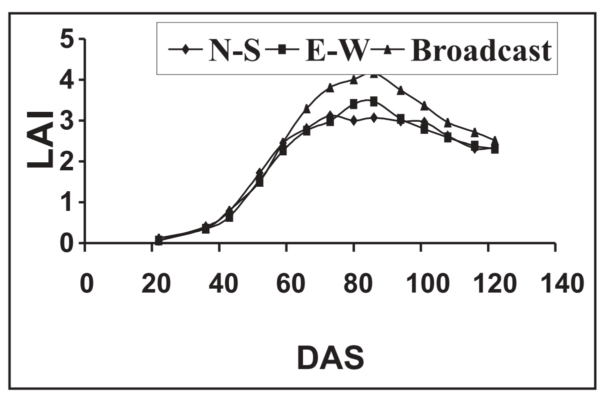

Fig. 2. Variation of LAI in Pusa Jagannath

Table 1: Mean for biomass and seed yield

Sowing	Mean biomass (g/m^2)			Mean yield (kg/ha)		
Direction (Treatment)	Pusa Agrani	Pusa Jagannath	Mean biomass	Pusa Agrani	Pusa Jagannath	Mean yield
North-South	450.0	647.0	548.5	1200.0	1333.3	1266.7
East-West	490.0	707.0	598.5	1283.3	1366.7	1325.0
Broadcast	600.0	780.0	690.0	1209.0	1372.0	1290.5
Mean	513.3	711.3		1230.8	1357.3	

For Mean biomass: CD(var) = 34.34 , CD(trt) = 42.06, CD(var*trt) = 59.48
For Mean yield : CD(var) = 14.85 , CD(trt) = 18.19 , CD(var*trt) = 25.72

Table 2: Mean for AET and WUE

Sowing	Mean AET (mm)			Mean WUE (g/m^2/mm of water)		
Direction (Treatments)	Pusa Agrani	Pusa Jagannath	Mean AET	Pusa Agrani	Pusa Jagannath	Mean WUE
North-South	58.7	66.3	62.5	7.7	9.8	8.7
East-West	73.6	68.6	71.1	6.7	10.3	8.5
Broadcast	76.9	81.4	79.1	7.8	9.6	8.7
Mean	69.8	72.1			7.4	9.9

For mean AET : CD(var) = 2.6852, CD(trt) = 3.2887, CD (var*trt) = 4.65
For mean WUE : CD(var) = 0.16 , CD(trt) = 0.20 , CD(var*trt) = 0.28

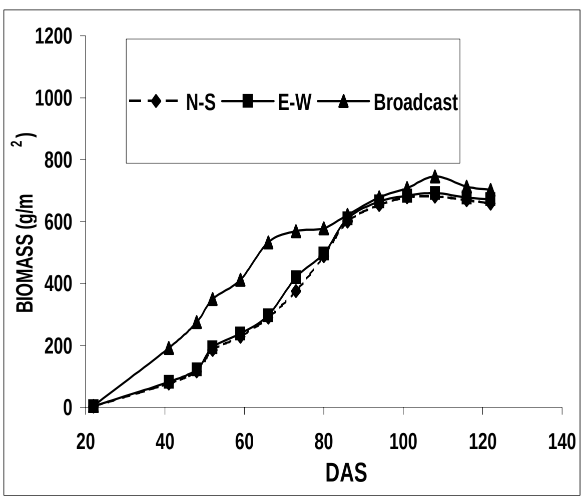

Fig. 3. Variation of biomass in Pusa Agrani

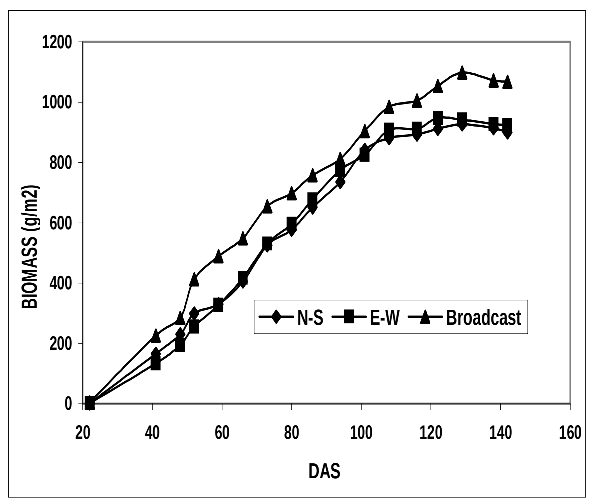

Fig. 4. Variation of biomass in Pusa Jagannath

Table 3: AET, WUE, biomass, yield and harvest index in different direction of sowing for Pusa Agrani

Pusa Agrani	AET (mm)	WUE (g/m2/mm of Water)	BIOMASS (g/m2)	YIELD (kg/ha)	H.I.
North-South	58.74	7.66	450	1200	0.26
East-West	73.64	6.65	490	1283	0.27
Broadcast	76.86	7.81	600	1209	0.23

result showed agreement with the findings reported by Sumana Roy (2003) that the leaf area index in the cultivar Pusa Agrani (*Brassica juncea*) varies from 2.3 to 4.4 and the rate of development of leaf is faster from about 50 days after sowing. The peak biomass values in North-South and East-West directions were 681 g/m^2 and 692 g/m^2, respectively in Pusa Agrani. The peak biomass observed in broadcast plot was 746 g/m^2 in this variety. The maximum biomass production~~s~~ in North-South and East-West directions were found to be 927 g/m^2 and 942 g/m^2, respectively, whereas the value in the broadcast plots was 1098 g/m^2 in Pusa Jagannath. Beyond the maximum LAI the broadcast plots also followed nearly same rate in Pusa Agrani Beyond the maximum LAI there was slight reduction in biomass due to leaf fall, senescence and drying irrespective of all directions of sowing. The analysis showed that the differences in final biomass for both variety wise and direction-wise were highly significant at 1% level (table1). Pusa Jagannath (with mean 711.33 g/m^2) produced more biomass than that of Pusa Agrani (with mean 513.33 g/m^2). The broadcast plots produced the highest biomass (mean 690 g/m^2) followed by the East-West sown plots (mean 598.5 g/m^2), and the North-South sown plots (mean 548.5 g/m^2). More number of plants/m^2 was the cause for highest biomass production/m^2 in broadcast plots, though the biomass/plant in broadcast plots produced was lower.

Variations of water use of efficiency (WUE) for the whole crop duration in the North-South, East-West, and broadcast in Pusa Agrani, and Pusa Jagannath are presented in table 3 & 4. In Pusa Agrani, WUE in the North-South, East-West, and broadcast were 7.66, 6.65 and 7.81 g/m^2/mm of water respectively, whereas the same in Pusa Jagannath were 9.76, 10.30 and 9.58 g/m^2/mm of water for the whole crop duration. But among the directions, and varieties it was found for the whole crop duration the accumulated AET in the East-West (especially for the Pusa Agrani) was higher than that in the North-South direction of sowing (table 3). This might have caused the reduction in WUE in the East-West direction of sowing in Pusa Agrani.

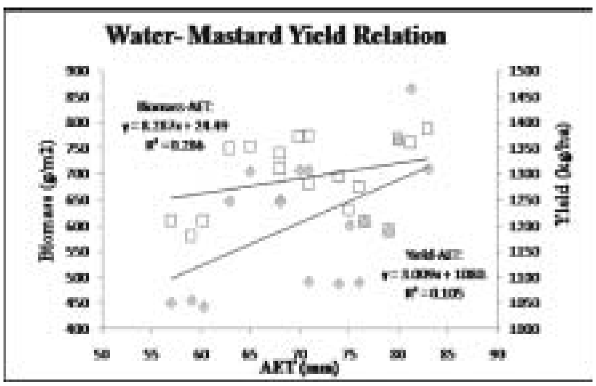

Fig. 5. Water and yield production function of mustard irrespective of any direction of sowing (blue rhombus: Biomass-AET data; red square: Yield-AET data)

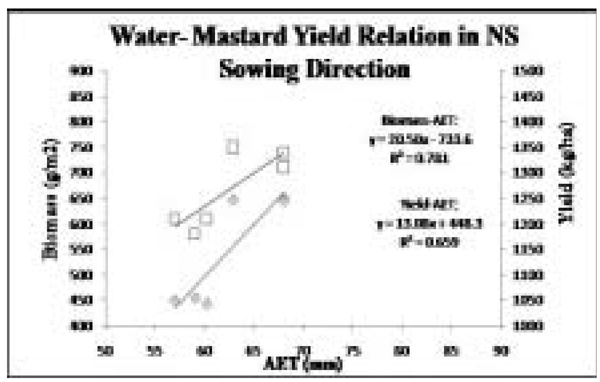

Fig. 6. Water and yield production function of mustard in North-South sowing direction (blue rhombus: Biomass-AET data; red square: Yield-AET data)

Table 4: AET, WUE, Biomass, yield and harvest index in different direction of sowing for Pusa Jagannath

Pusa Jagannath	AET (mm)	WUE (g/m2/mm of Water)	BIOMASS (g/m2)	YIELD (kg/ha)	H.I.
North-South	66.30	9.76	647	1333	0.19
East-West	68.63	10.30	707	1367	0.21
Broadcast	81.42	9.58	780	1372	0.18

This result of ET being higher in EW directionally sown crop than that in NS one proved in agreement with the results reported by Steiner (1986) in sorghum crop. The aerodynamic effect might be the main cause of reduction in ET values in N-S directional sowing because rows perpendicular to the wind tended to generate more turbulence than rows parallel to the wind (Lemon *et al.*, 1963; Chinchoy *et al.*, 1977). The analysis showed that the differences in WUE among the varieties were highly significant at 1% level whereas among directions (North-South, East-West and broadcast) those were significant at 5% level (table 2). The WUE of Pusa Jagannath (with mean 9.9 g/m2/mm) was higher than that of Pusa Agrani (with mean 7.4 g/m2/mm). Among the directions of sowing, differences in the WUE in the North-South (with mean 8.7 g/m2/mm) and broadcast (with mean 8.7 g/m2/mm) were non-significant irrespective of varieties. But the WUE in the East-West directionally sown plots (with mean 8.48 g/m2/mm) differed significantly from that in North-South, and broadcast plots (table 2). Between the directions the North-South sown plots had higher WUE than that in the East-West sown plots due to less accumulated AET for the whole crop duration in the North-South sown plots irrespective of varieties. The results shows conformity with the findings reported by Ram Niwas *et al.* (1997) in pearl millet crop where the WUE was reported to be higher in NS directionally sown plots than that in EW sown plots.

Seed yields in Pusa Agrani in North-South, East-West, and broadcast plots were 1200, 1283 and 1209 kg/ha, respectively, and the same in Pusa Jagannath were 1333, 1367 and 1372 kg/ha, respectively. From the analysis it is evident that differences in seed yields of two varieties were highly significant at 1% level, with Pusa Jagannath (mean 1357 kg/ha) yielded better than Pusa Agrani (mean 1231 kg/ha) (table 1). The differences in yields in North-South, East-West and broadcast plots also were significant at 1% level (Table1), with the East-West direction

Table 5: ANOVA for harvest index (HI)

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Var	1	84.58	84.58	7.46	0.0182*
Treat	2	6.10	3.05	0.27	0.7686
Rep	2	13.73	6.86	0.61	0.5618
Error	12	136.08	11.34		
Corrected Total	17	240.49			

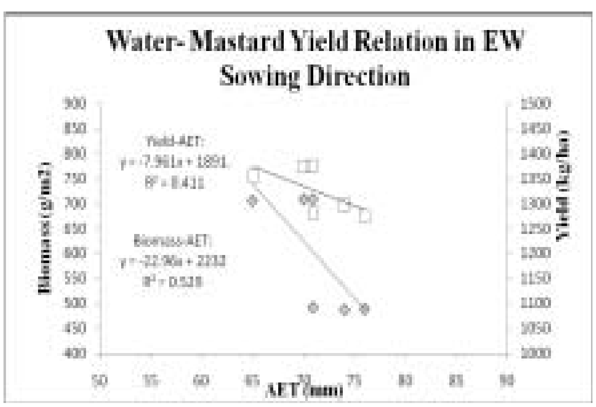

Fig. 7. Water and yield production function of mustard in East-West sowing direction (blue rhombus: Biomass-AET data; red square: Yield-AET data)

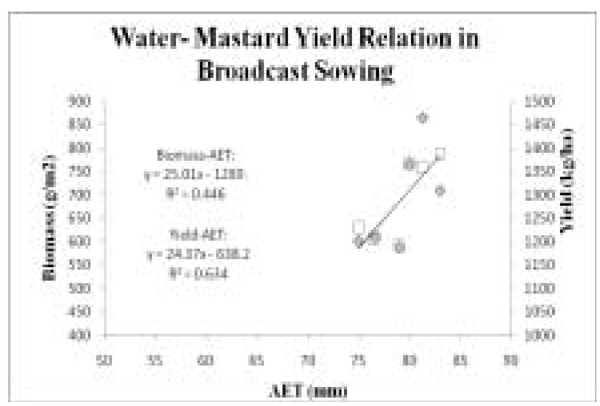

Fig.8. Water and yield production function of mustard in broadcast sowing (blue rhombus: Biomass-AET data; red square: Yield-AET data)

(mean 1325 kg/ha) yielded best followed by the broadcast method (mean 1291 kg/ha), and North-South directional sowing (mean 1267 kg/ha). The yields found in different directions of sowing are in opposite trend with the findings of Dhingra *et al*., 1986 (wheat crop), Grewal *et al*., 1989 (Pearl millet) and Kler *et al.*, 1989 (wheat crop) where the average yield of crops were higher in North-South than that in East-West direction of sowing. But the result of present study is in agreement with the results reported by Suraj Bhan *et al*., 1995 and Mahto *et al.*, 2001 who studied with the *Brassica sp.* After attaining the peak value, the biomass of Pusa Agrani decreased to reach the final value of 450, 490 and 600 g/m^2 in north south, East-West and broadcast plots, respectively at the time of harvest. The same in Pusa Jagannath were 647, 707 and 780 g/m^2, respectively. The analysis of data showed that the differences in final biomass for both variety wise and direction-wise were highly significant at 1% level (table1). Pusa Jagannath (with mean 711.33 g/m^2) produced more biomass than that of Pusa Agrani (with mean 513.33 g/m^2). The broadcast plots produced the highest biomass (mean 690 g/m^2) followed by the East-West sown plots (mean 598.5 g/m^2), and the North-South sown plots (mean 548.5 g/m^2). More number of plants/m^2 was the cause for highest biomass production/m^2 in broadcast plots, though the biomass/plant in broadcast plots produced was lower. Harvest Index (HI) of Pusa Agrani in North-South, East-West, and broadcast were 0.26, 0.27, and 0.23, respectively. Contrary to it, the same in Pusa Jagannath were 0.19, 0.21, and 0.18, respectively (tables 3 & 4). The ANOVA showed that the differences among the HI of North-South, East-West or broadcast were non-significant, whereas the difference between the HI of two varieties was significant at 5% level (Table 5) and the Pusa Agrani (with mean value 0.25) had higher HI than Pusa Jagannath (with mean value 0.21).

Figures 5, 6, 7 & 8 illustrate the water and yield or biomass relation with respect to irrespective of any direction, North-South sown direction, East-West sown direction and broadcast sown plots, respectively. Figures of the AET-yield production function illustrate that North-South directional sowing Indian mustard crop has a higher coefficient of determination than East-West, and broadcast sown crops. Figure 6 & 7 also revealed that there was an altered AET-yield production function when the direction of sowing is changed from North-South to East-West. Nielsen & Vigil (2014) studied the synergism in the dryland cropping system in the central Great Plains, and found changes in WUE due to crop rotation as evaluated from the slopes of water use/yield production function.

Conclusions

The accumulated actual evapotranspiration for the whole crop duration, and the maximum value of actual evapotranspiration (AET) were higher in East-West than North-South direction of sowing in both the erect as well as the spreading type of varieties. The Water Use Efficiency (WUE) for the whole crop duration was higher in the North-South direction than East-West in both the varieties. The AET-yield production function also showed a good relation in the North-South directional sowing. This is due to the fact that seasonal AET was less in North–South direction than East–West direction. Harvest index and yield were higher in East-West than North-South direction of sowing in both the varieties due to higher AET in East-West direction. Yield differed significantly between the two directions of sowing. Biomass, LAI, WUE and yield were recorded more in the broadcast plots than both of the directionally sown plots due to higher density of plant stands per unit area in broadcasted plots. As the plant density is not uniform in broadcast plots and there are problems related to inter-cultural operation, and management of those plots, farmers are not recommended to follow the practice of sowing by broadcasting. So, it is evident from the above study that the East-West directional sowing is the best direction in relation to yield, and growth of the Indian mustard crop, grown during the *rabi* season in North – West part of India.

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