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Research Article

Evaluation of Spatio-temporal dynamics in agriculture in arid and semiarid region of Rajasthan, India-A statistical approach

Sonia
Department of Arts, School of Liberal Arts and Sciences, Mody University of Science and Technology, Lakshmangarh, Sikar (Rajasthan), India
Sunita
Department of Arts, School of Liberal Arts and Sciences, Mody University of Science and Technology, Lakshmangarh, Sikar (Rajasthan), India
Tathagata Ghosh*
Department of Arts, School of Liberal Arts and Sciences, Mody University of Science and Technology, Lakshmangarh, Sikar (Rajasthan), India

*Corresponding author. E-mail: tathagatawork@gmail.com

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Abstract
The aridity of the arid and semiarid region of Rajasthan, India is considered as a great challenge for the growth of the crops due to lack of precipitation and high range of temperature. The present study focused on evaluating agricultural dynamics of the arid and semi-arid region of Rajasthan for the period of 2008-09 and 2021-22. The study comprised seven districts of Rajasthan: Barmer, Bikaner, Churu, Ganganagar, Hanumangarh, Jaisalmer and Jodhpur. Indices like crop combinations, crop diversity and agricultural efficiency of crops were taken into consideration. Hanumangarh showed 8 crop combinations to 4 from past to recent years viz. Bajra (*Pennisetum glaucum*), Guar seed (*Cyamopsis tetragonoloba*), Kharif pulses (Without Arhar) and Moth (*Vigna aconitifolia*), while in Jaisalmer, it was 3 crop combinations in the past while it is 6 in the recent years viz. Bajra, Guar seed , Moth , Mustard (*Brassica*), Mung (*Vigna radiata*) and Groundnut(*Arachis hypogaea*). A small percentage of Seasamum (*Sesamum indicum*) and Cotton (LINT)(*Gossypium*) was in the past previous years, but now, it is almost negligible. Wheat (Triticum) was observed in a lower to moderate percentage share throughout the period. There was no change in the dominant crops except in Ganganagar and Churu district. All the districts had higher crop diversification in recent years except Barmer. The result of agricultural efficiency showed that Ganganagar, Jodhpur, Hanumangarh had higher agricultural efficiency (> 100), while Barmer had the least value (< 50). Agricultural Indices efficiently visualized temporal agriculture trends in arid and semiarid regions of Rajasthan.

Keywords: Agricultural dynamics, Agricultural efficiency, Crop combination, Crop diversification

INTRODUCTION

Agriculture is a dynamic sector of the economy that has evolved. It is one of the major land use worldwide as it is directly associated with the increasing need of the growing population. It is projected that, to meet the future need of the food demand in the near future; phenomenal increase in agricultural production is expected (Tian *et al*., 2021, Aryal *et al*., 2022). With time, various inputs in agriculture have changed the entire scenario in terms of larger-scale production in at relatively small period of time (Yang *et al*., 2022, Pawlak and Kołodziejczak, 2020). Still, the climatic condition is one of the most important factors in a lot of places around the world. The climate of any region has a direct and crucial impact on the overall agricultural character of that region. Variation in climate can lead to considerable variability in the nature of agriculture as a whole (Arora, 2019, Zhang *et al*., 2017, Wiebe *et al*., 2015). Agriculture in arid and semiarid region has its own limitations, which has a direct result on the agricultural productivity (Duraisamy *et al*., 2018, Kar 2014). To understand the need of present as well as the future, regionalization of agriculture according to its potentiality is one of the important dimensions of agricultural science as a whole at the same time in the arid and semiarid regions per se (Husain 2010). There are many methods through which many scholars have attempted

regionalization. Crop combination is a widely used method through which the relationship among different crops associated with land utilization can be observed (Nemecek *et al*., 2015, Iqbal, 1979). In recent years the importance of crop combination has increased to utilize the land to its maximum and make provision for better output from the same land. Conventional crop combination is an important method that not only gives an understanding of individual crops but also about combination between the crops (Gaikwad *et al*., 2019, Shafi 2006). For the crop combination model, J.C.Weaver's model (Weaver 1954) is widely used and has its importance to date. He has proposed the model in the Middle West. The result showed that the model successfully depicted crop combination regions. Crop diversification is agricultural practice through crop rotation and intercropping of crops belonging to the same or different species (Francaviglia *et al*., 2020, Makate 2016, Piedra-Bonilla *et al*., 2020). According to (Njeru 2013), crop diversification is feasible and cost-effective method as it can reduce uncertainties in agriculture. Other than that, crop diversification is an effective method of maintaining soil fertility and control of parasites (Li *et al*., 2023, Truscott *et al*., 2009). Agricultural efficiency is one of the acknowledged indexes. It shows the collective performance of different crops per hectare output capacity (Chivu *et al*., 2020). Sapre and Deshpande (1964) have shown inter-state variation in the agricultural efficiency of Maharashtra state. The conclusion showed that rainfall played an important role in the inter-state agricultural efficiency pattern. A similar approach has been adopted by many scholars in their study to depict agricultural efficiency at regional and global scales (Lyu *et al*., 2021, Cardozo *et al*., 2018). In the present study, an effort has been made to look into the spatio-temporal agricultural dynamics in the semiarid to arid northwestern segment of Rajasthan, India, using significant methods like crop combination, crop diversity and agricultural efficiency performed to depict the potential dynamics in agriculture.

MATERIALS AND METHODS

Study area

The study area of the present work is located in the western segment in the state of Rajasthan, comprising an area of 1,54,346 km^2 between 24º 41' 19.69" north to 30º 12' 08.60" north latitude 69º 18' 41.91'' east to 75°40'20'' east longitude (Hydrogeological Atlas of Rajasthan (2013), Bhalla and Bhalla 2013) (Fig.1). The study area comprises the districts of Barmer, Bikaner, Churu, Ganganagar, Hanumangarh, Jaisalmer and Jodhpur. In the west and northwest, it shares the international boundary with Pakistan. In the south, the study area merges with the state boundary of Gujarat. In the east, it shares the district boundaries of Rajasthan, namely Jhunjhunu, Sikar, Nagaur, Pali and Jalore, while in the northeast, it adjoins the state boundary of Haryana as well as Punjab. Most of the study area is associated with low and undulating topography stabilising the area and active dunal plains (Hydrogeological Atlas of Rajasthan (2013). Majority of the study area is associated with sandy soil (Bhalla and Bhalla, 2013). As the study area falls in the arid to semiarid climatic region, extreme temperature range was one of the characteristic features. In the arid region, the average temperature was more than 34 °C during the summer, while the winter varies between 12°C to 16°C. In the semiarid region the temperature during winter ranges between 10°C to 17°C, while during the summer, it ranges between 32°C to 36°C. The rainfall ranges between less than 10cm to 20cm in the arid region, while in the semiarid region the rainfall varies between 20cm to 40cm. During 2008-09 and 2017-18, the erratic nature of rainfall was observed in terms of average rainfall and mean monthly rainfall (Agricultural Statistics of Rajasthan 2007-08 and Agricultural Statistics 2018-19).

Data analysis

The present study was based on secondary-level data. Agricultural statistics for the year 2008-2009 and 2021-22 were collected from the official website of the Department of Agriculture, Government of Rajasthan (https://www.tourism.rajasthan.gov.in/content/agriculture/en/Agriculture-Department-dep/agriculture-statistics.html accessed on 10-01-2023). Seven of the districts, namely Barmer, Bikaner, Churu, Ganganagar, Hanumangarh, Jaisalmer and Jodhpur were taken into consideration as all of them fall in the arid to semiarid climatic region (Bhalla and Bhalla, 2013). Data regarding the area under all the crops and the yield of the corresponding crops were tabulated for individual districts. District census handbooks (2011) were collected from Census of India (https://censusindia.gov.in/2011census/dchb/RajastanA.html accessed on 10-01-2023) for fundamental information about the selected districts. For regionalization, three methods are adopted. This study adopted J.C. Weaver's method (1954) of Crop Combination. Weaver proposed least standard deviation technique for the calculation of crop combination (Weaver 1954). The theory considers the theoretical curve for the standard measurement of area under different crop types and the actual area percentage under different crops. Weaver has incorporated up to ten crops in his proposed model.

For the calculation, the following formula (1) of standard deviation (σ) is taken into consideration-

$$\sigma = \sqrt{\frac{\sum d^2}{n}} \quad (1)$$

Here, *d* is the difference between the actual crop per-

centage in a given area and the percentage area in the theoretical curve, *n* is the total number of crops in the given combination. As the model deals with the relative magnitude of deviation and not the actual magnitude of deviation, hence Weaver did not consider the square root in his model. Therefore, the actual formula (2) used in the model by Weaver is as follows-

$$\text{Crop combination(S)} = \frac{\sum d^2}{n} \quad (2)$$

In the present work, all crops that constitute up to 95% of the total cropped area are considered significant crops for further calculation.

Crop diversification is another way of understanding how far diversification is occurred in cropping. For calculation of crop diversification, Gibbs and Martin's index of diversification (1962) is a widely used measurement (3).

$$\text{Crop diversification (d)} = 1 - \frac{\sum x^2}{(\sum x)^2} \quad (3)$$

Here *x* is the % of the total cropped area occupied by individual crops.

In the present work, all of the crops found significant through crop combination indexes through crop combination model are considered for the crop diversification depiction. Based on the results the selected districts were categorized under three categories, viz. low, moderate and high.Agricultural efficiency is considered an important indicator that shows how well the agricultural land is utilized under different crops. Different factors like land size holdings, market structure, crop rotation, cropping pattern are associated with the agricultural efficiency. The present study calculated agricultural efficiency using S.S.Bhatia's method (Bhatia 1967) (4 and 5). In the case of agricultural efficiency, area under all the important crops and yield area were considered. The formula for calculation of Agricultural efficiency is-

$$Ei = \frac{\sum Iij \; X \; Cij}{\sum Cij} \quad (4)$$

To calculate *Iij* the following formula is applied (5) –

$$Iij = \frac{Yij}{Yi} \; X \; 100 \quad (5)$$

Here-

Ei = Agricultural Efficiency, *Iij* = Ratio of Yield of any crop (*Yij*) of the individual area 'i' under the total cropped area and the average yield rate (*Yi*) of the entire area of any crop multiplied by 100, *Cij* = Area in % for the distinct crop in an individual area.

Like crop diversification, the districts were categorized into three categories based on the agricultural efficiency index (low, moderate and high).The results obtained from the crop combination, crop diversification and agricultural efficiency were incorporated in ArcGIS 10.2 software for the comparative representation through mapping for the year 2008-09 and 2021-22.

Fig. 1. *Location map of the study area.*

RESULTS AND DISCUSSION

For the year 2008-09, crop combination of Barmer depicted four crop combinations with significant crops like Bajra (*Pennisetum glaucum*), Guar seed (*Cyamopsis tetragonoloba*), Kharif pulses (Without *Cajanus cajan*) and Moth (*Vigna aconitifolia)* in descending order. Similarly, Bikaner had four crop combinations with major crops like Guar seed(*C. tetragonoloba*), Kharif pulses (Without *C. cajan*), Mung (*V. radiata*) and Bajra (*P. glaucum*). Smaller percentage of Seasamum (*S. indicum*) and Cotton (LINT) (Gossypium) was observed in the previous years but in recent years, their percentage is negligible. Relatively lower to moderate percentage share of Wheat (*Triticum*) was observed in 2008-09 and 2021-22. Churu and Ganganagar showed a penta crop combination. Jaisalmer depicted the least crop combination (tri), while Hanumangarh and Jodhpur depicted higher crop combinations (octa and nona, respectively). During this period, in all the districts, Bajra (*P. glaucum*) and Guar seeds (*C. tetragonoloba*) were the dominant crops (Table 1). For the year 2021-22, the crop combination index result showed that Jaisalmer was associated with six crop combinations with significant crops like Guar seed (*C. tetragonoloba*), Gram (*C. arietinum*), Bajra (*P. glaucum*), Mustard (*Brassica*), Groundnut (*A. hypogaea*) and Mung (*V. radiata*). Barmer, Bikaner, Churu, Ganganagar and Jodhpur were associated with penta crop combinations. On the other hand, Hanumangarh had quadra crop combination. In Bikaner, Hanumangarh and Jaisalmer Guar seed (*C. tetragonoloba*) was the dominant crop. The dominant crop was in Barmer and in

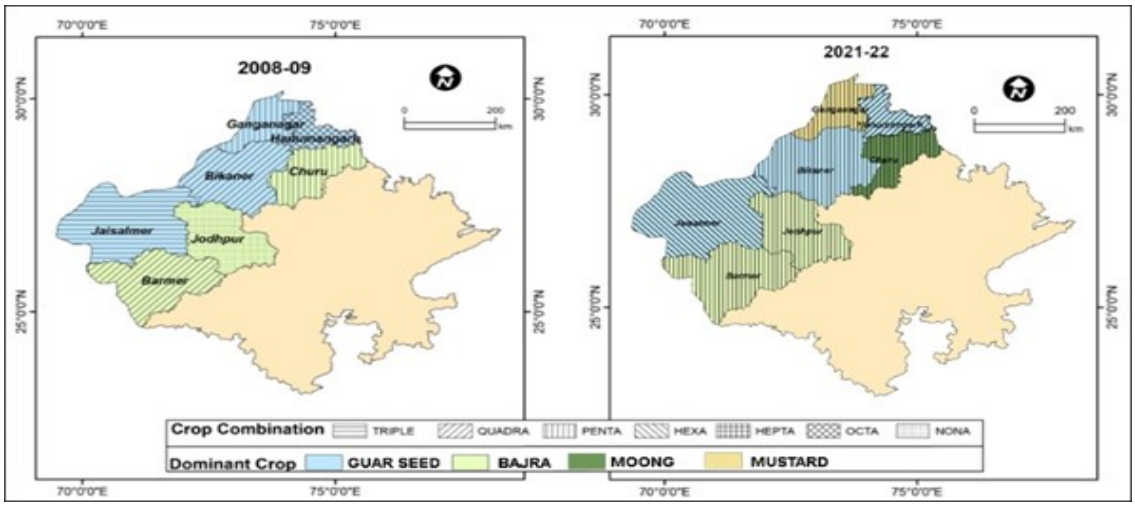

Fig. 2. *Crop combination and dominant Crops of selected districts of Rajasthan (2008-09 and 2021-22)*

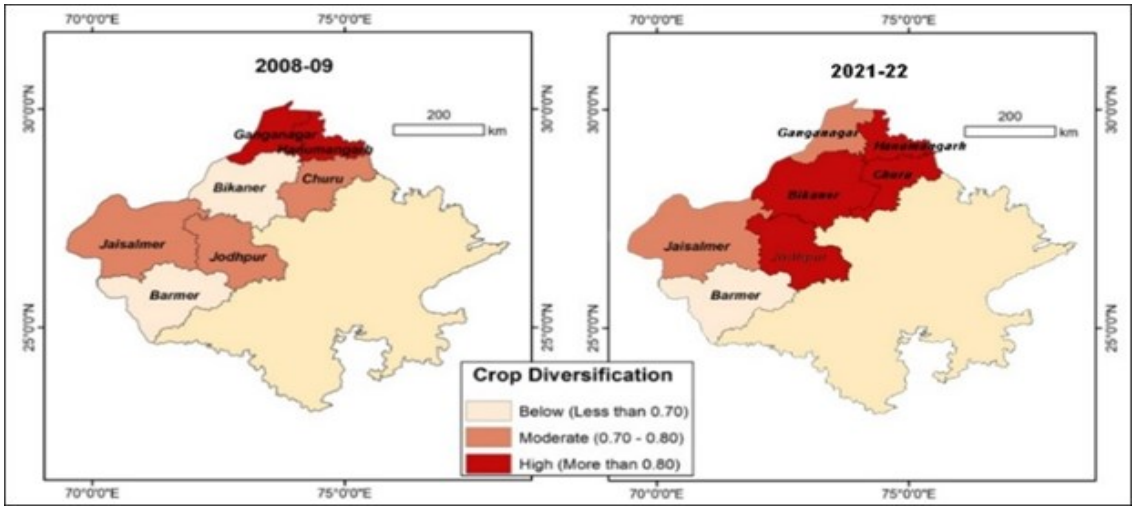

Fig. 3. *Crop diversification of selected districts of Rajasthan (2008-09 and 2021-22)*

Jodhpur Bajra (P. glaucum). Churu and Ganganagar showed Mung (*V. radiata*) and Mustard (*Brassica*) as dominant crops, respectively (Table 2) (Fig.2). During 2008-09 the crop combination ranged between three in Jaisalmer and nine in Jodhpur. Districts like Barmer and Bikaner had crop combinations of four, while Churu and Ganganagar were associated with five crop combinations and eight crop combinations were found in Hanumangarh. The dominant crop during 2008-09 in Barmer, Churu and Jodhpur was Bajra while in Bikaner, Ganganagar, Hanumangarh and Jaisalmer, the dominant crop was Guar seed (Table 3). Fewer crop combinations indicate market economy-based cultivation, while increasing crop combinations generally indicate uncertainty of the climatic and economic resources (Weaver 1954). Each crop combination is unique and reflects the specific environmental, cultural, and economic conditions of the region in which it is found (Beach *et al*., 2019). Considerable variation in crop diversification was observed among selected districts and between the selected period. In 2008-09, the diversification index varied between 0.72 (Jaisalmer) to 0.81 (Hanumangarrh and Ganganagar). On the other hand, during 2021-22, maximum diversification was observed in Churu, while minimum diversification was found in Barmer with a diversification index of 0.84 and 0.57, respectively (Table 4). During 2008-09, Bikaner and Barmer were categorized under low crop diversification (below 0.70), while during 2021-22, Barmer was in low crop diversification. In the next category (0.71-0.80) Jaisalmer, Jodhpur and Churu were present in 2008-09, while in 2021-22, Ganganagar and Jaisalmer were categorized in this category. During 2008-09, Hanumangarh and Ganaganagar ranked highest in terms of crop diversity (more than 0.80), while in 2021-22, Bikaner, Churu and Jodhpur were added with Hanumangarh and these four districts ranked highest in crop diversity (more than 0.80) (Fig.3; Table 5). Single nutrient deficiency problem was another issue related to the decreasing soil nutrients due to growing similar crops. Hence, crop diversification is one of the important methods (Wang *et al*., 2022). Over the time period, it is ob-

Table 1. Crop combination index results for selected districts of Rajasthan (2008-09)

Sr. No.	Name of the District	Crop Combination index									Crops
		Mono	Double	Triple	Quadra	Penta	Hexa	Hepta	Octa	Nona	
1	Barmer	2349.87	499.97	338.22	**290.05**	304.58					B,G,Ka, **M**
2	Bikaner	2844.85	630.97	293.86	**204.47**	275.64					G,Ka,M,**B**
3	Churu	5778.40	800.39	166.92	36.59	**9.16**	15.23				B,G,Ka,M,**Gr**
4	Ganganagar	5934.08	772.78	143.59	57.82	**48.50**	62.56				G,Mu,W, Gr, **C**
5	Hanuman-garh	5022.30	786.42	206.07	107.26	79.82	68.61	65.92	**64.84**	75.65	G,W,Gr, Rc, Mu, B, Ka, **M**
6	Jaislamer	3983.03	308.75	**124.90**	152.33						G,M, **B**
7	Jodhpur	3932.56	646.36	282.55	177.17	144.12	126.26	121.93	116.1	**110.43**	B,Ka,M,G,Mu n,Mu,S,W,**Gr**

Crops: B-Bajra, G-Guar Seed, Ka- Kharif Pulses (Without Arhar), M-Moth, Gr-Gram, Mun-Mung, Mu-Mustard, S-Seasamum, W-Wheat, Gn-Groundnut, C-Cotton (LINT). Significant index values are marked in bold; Source: Computed by the Authors

Table 2: Crop combination index results for selected districts of Rajasthan (2021-22)

Sr. No.	Name of the District	Crop Combination index									Crops
		Mono	Double	Triple	Quadra	Penta	Hexa	Hepta	Octa	Nona	
1	Barmer	1426.30	618.76	523.13	516.39	**448.32**	478.24				B,G,M,Mu,**Mun**
2	Bikaner	5219.54	686.10	216.69	92.95	**53.97**	53.99				G,M,Gn,Mu,**Gr**
3	Churu	5799.95	810.65	170.29	63.54	**33.94**	41.04				Mo,M,Gr,B,**Mu**
4	Ganganagar	3592.99	503.85	165.46	109.45	**126.15**	148.60				Mu,W,Mo,G,**Gr**
5	Hanuman-garh	5475.83	740.12	146.14	**33.21**	37.53	56.05				G,Mu,Gr,**W**
6	Jaisalmer	2692.57	510.41	267.98	250.78	244.66	**230.03**	259.60			G,Gr,B,Mu,Gn, **Mun**
7	Jodhpur	5009.04	668.14	180.10	89.99	**60.58**	66.04				B,Mun,Mu,Gn, **G**

Crops: B--Bajra, G--Guar Seed, Ka-- Kharif Pulses (Without Arhar), M-- Moth, Gr--Gram, Mun--Mung, Mu--Mustard, S--Seasamum, W--Wheat, Gn—Groundnut; Significant index values are marked in bold**;** Source: Computed by the Authors

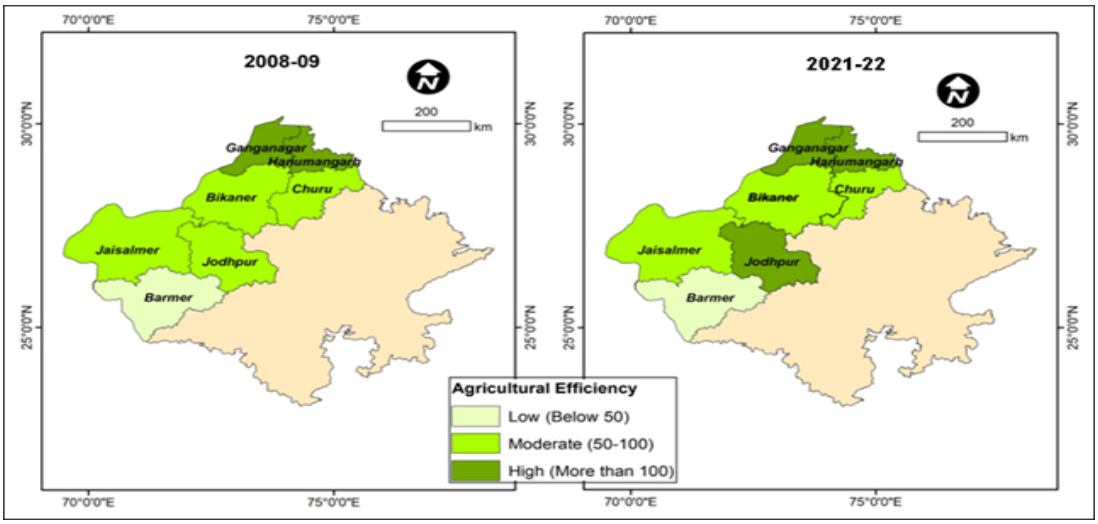

Fig. 4. *Agricultural efficiency of selected districts of Rajasthan (2008-09 and 2017-18)*

served that in all the districts, number of crop combinations as well as crop diversification. In recent years, Barmer showed lower crop diversification and five crop combinations, which might result from lack of irrigation, low rainfall, low soil quality and high risk of crop failure (Prasad and Maravi, 2021, Nisha 2015, Chandra, 2013). Ganganagar and Jaisalmer showed moderate crop diversification in recent years, which might be related to the introduction of high-yielding variety seeds and other modern implements in agriculture (Prasad

and Maravi, 2021). On the other hand, Bikaner, Churu, Hanumangarh, and Jodhpur depicted high crop diversification, which has a strong relation with better irrigational facilities, and expertise in modern implements of agriculture (Prasad and Maravi, 2021). During 2008-09, agricultural efficiency among the selected districts ranged between 23.00 and 188.23 Ganganagar showed the highest efficiency (188.23), while Barmer had the lowest efficiency (23.00). During 2021-22, the range of agricultural efficiency was 32.12 to 140.97 Barmer and Ganganagar depicted the lowest and highest agricultural efficiency, respectively (Table 6). Hence, in terms of highest and lowest agricultural efficiency, there was no change in the position in recent years; the increasing value showed a definite increase in agricultural efficiency. As per the categorization of agricultural efficiency index, Barmer was categorized under low agricultural efficiency in both years. Regarding moderate agricultural efficiency (50-100), four districts, namely Churu, Bikaner, Jodhpur, and Jaisalmer, were there during 2008-09.On the other hand, in the recent year (2021-22), three districts (Bikaner,Churu and Jaisalmer) are present in the category (Fig.4). In the category of high agricultural efficiency (more than 100), Ganganagar and Hanumangarhwere present in the previous years (2007-08)(Table 7). In the recent year (2021-22), one more district (Jodhpur) was added with Ganganagar and Hanumangarh. Results obtained from three methods adopted in the present work depicted some of the significant outcomes of the study area. The present scenario's higher level of agricultural efficiency among these districts indicated better agricultural land usage, use of modern implements, better irrigational facility and market awareness (Biswas, 2022, Dutta 2012). Crop combination analysis successfully depicted the crop combinations and the dominant crops. In recent years, overall crop combinations had increased with the exceptions like Churu and Ganganagar where the crop combinations were the same.In Hanumangarh, crop combination had decreased from 8 to 4; in Jodhpur, it had decreased from 9 to 5. Crop diversification results showed other important dimensions of crop dynamics. Only Barmer did not change its position regarding the index, while the rest of the districts showed positive changes in their relative position over the years. Bikaner, Churu, Hanumangarh and Jodhpur show the highest crop diversification (more than 0.80) among the selected districts in recent years. At the same time, Ganaganagar, Jodhpur and Hanumangarh depicted the highest agricultural efficiency. Hence considering the districts like Ganganagar, Jodhpur, Hanumangah and Bikaner it can be observed that except Bikaner, none of the districts showed significant change in crop combination, but in terms of crop diversification and agricultural efficiency, these four districts showed considerable positive change.

Table 3. Crop combination and Dominant Crops

Sr. No.	Name of the District	2008-09		2021-22	
		Crop Combination	Dominant Crop	Crop Combination	Dominant Crop
1	Barmer	4	Bajra	5	Bajra
2	Bikaner	4	Guar Seed	5	Guar Seed
3	Churu	5	Bajra	5	Mung
4	Ganganagar	5	Guar Seed	5	Mustard
5	Hanumangarh	8	Guar Seed	4	Guar Seed
6	Jaisalmer	3	Guar Seed	6	Guar Seed
7	Jodhpur	9	Bajra	5	Bajra

Source: Computed by the Authors

Table 4. Crop diversification index of the selected districts

Districts	Crop Diversification index	
	2008-09	2021-22
Jaislamer	0.72	0.57
Barmer	0.61	0.83
Bikaner	0.67	0.84
Hanumangarh	0.81	0.75
Ganganagar	0.81	0.82
Churu	0.80	0.71
Jodhpur	0.77	0.83

Source: Computed by the Authors

Table 5. Categorization of selected districts based on crop diversification

Category	2008-09	2021-22
Low (Below 0.70)	Bikaner, Barmer	Barmer
Moderate (0.71-0.80)	Jaisalmer, Jodhpur and Churu	Ganganagar , Jaisalmer
High (More than 0.80)	Hanumangarh and Ganganagar	Bikaner, Churu, Hanumangarh, Jodhpur

Source: Computed by the Authors

Table 6. Agricultural efficiency index of the selected districts

Districts	Agricultural efficiency	
	2008-09	2021-22
Barmer	23.00	32.12
Bikaner	91.67	98.36
Churu	94.12	84.04
Ganganagar	188.23	140.97
Hanumangarh	188.05	122.58
Jaislamer	32.23	61.31
Jodhpur	68.93	106.34

Source: Computed by the Authors

Table 7. Categorization of selected districts based on agricultural efficiency

Category	2008-09	2021-22
Low (Below 50)	Barmer	Barmer
Moderate (50 -100)	Churu, Bikaner, Jodhpur, Jaisalmer	Bikaner ,Churu, Jaisalmer
High (More than 100)	Ganganagar, Hanumangarh	Ganganagar, Jodhpur, Hanumangarh

Source: Computed by the Authors

Conclusion

All three measurements, viz. combinations, crop diversity and agricultural efficiency in the arid and semiarid regions of Rajasthan throughout 2008-09 and 2021-22, showed a probable relationship among them. Previously, the crop combinations were more diversified as they ranged from three to nine viz. Bajra (*P. glaucum*), Guar seed(*C. tetragonoloba*), Kharif Pulses (without Arhar), Moth (*V. aconitifolia*), Gram (*C. arietinum*), Mustard (*Brassica*) and Groundnut (*A. hypogaea*)). But in recent years, the range was between four to six crop combinations viz. Bajra , Guar seed , Moth , Mustard , Mung (*V. radiata*) and Groundnut . Percentage share of Seasamum (*S. indicum*) and Cotton (LINT)(*Gossypium*) was observed in the past year with lower percentage but in recent years, it was insignificant. In 2008-09 and 2021-22 relatively lower to moderate percentage share of Wheat (*Triticum*) was observed. There was no significant change in the dominant crop in both periods. In previous years, the dominant crop in Churu was Bajra, but it has recently shifted to Mung . Similarly, Ganganagar's major crop shifted from Guar seed to Mustard. Agricultural efficiency and crop diversification somehow showed an important outcome: continuous upward movement of the selected districts towards better situations except for the district of Barmer. In the rest of the districts, noticeable dynamics in crop combination, crop diversity, and agricultural efficiency were observed. Hence, in terms of the overall nature of the region, there were significant crop dynamics in the agriculture of this region despite climatic restrictions.

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Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Agricultural Statistics of Rajasthan (2007-08). Retrieved 30 June 2021, <http://www.agriculture.rajasthan.gov.in/content/agriculture/en/Agriculture-Department-dep/agriculture-statistics/agriculture-statistics-at-a-glance>.
2. Agricultural Statistics of Rajasthan (2018-19). Retrieved 30 June 2021, <http://www.agriculture.rajasthan.gov.in/content/agriculture/en/Agriculture-Department-dep/agriculture-statistics/agriculture-statistics-at-a-glance>.
3. Arora, N. K. (2019). Impact of climate change on agriculture production and its sustainable solutions. *Environmental Sustainability*, 2(2), 95-96.
4. Aryal, J. P., Manchanda, N. & Sonobe, T. (2022). Expectations for household food security in the coming decades: A global scenario. In Future Foods (pp. 107-131). Academic Press.
5. Biswas, B. (2022). Changing crop concentration and agricultural efficiency: a study in West Bengal, India. GeoJournal, 87(2), 491-513.
6. Beach, R. H., Sulser, T. B., Crimmins, A., Cenacchi, N., Cole, J., Fukagawa, N. K., ... & Ziska, L. H. (2019). Combining the effects of increased atmospheric carbon dioxide on protein, iron, and zinc availability and projected climate change on global diets: a modelling study. *The Lancet Planetary Health,* 3(7), e307-e317.
7. Bhalla., L. R., and Bhalla., K., 2013. Contemporary Rajasthan. Kuldeep Publication India.
8. Bhatia, S. S. (1967). Spatial variations, changes and trends in agricultural efficiency in Uttar Pradesh, 1953-1963. *Indian Journal of Agricultural Economics,* 22(902-2018-2012), :66-80.
9. Cardozo, N. P., de Oliveira Bordonal, R., & La Scala Jr, N. (2018). Sustainable intensification of sugarcane production under irrigation systems, considering climate interactions and agricultural efficiency. *Journal of Cleaner Production*, 204, 861-871.
10. Chandra, S. (2013). Crop Diversification Pattern: A Spatio

-Temporal Analysis in Haryana: 1990-93 & 2009-12. South -Asian Journal of Multidisciplinary Studies (SAJMS), 5(1), 73-89.
11. Chivu, L., Andrei, J. V., Zaharia, M., & Gogonea, R. M. (2020). A regional agricultural efficiency convergence assessment in Romania–Appraising differences and understanding potentials. *Land Use Policy*, 99, 104838.
12. Department of Agriculture, Government of Rajasthan (https://www.tourism.rajasthan.gov.in/content/agriculture/en/Agriculture-Department-dep/agriculture-statistics.html accessed on 10-01-2023)
13. District census handbooks (2011): (https://censusindia.gov.in/2011census/dchb/RajastanA.html accessed on 10-01-2023)
14. Duraisamy, V., Bendapudi, R. & Jadhav, A. (2018). Identifying hotspots in land use land cover change and the drivers in a semiarid region of India. *Environmental Monitoring and Assessment*, 190(9), 535.
15. Dutta, S. (2012). Assessment of agricultural efficiency and productivity: A study of Hugli district, West Bengal, India. *International Journal of Current Research*, 4(11), 190-195.
16. Francaviglia, R., Álvaro-Fuentes, J., Di Bene, C., Gai, L., Regina, K., & Turtola, E. (2020). Diversification and management practices in selected European regions. A data analysis of arable crops production. *Agronomy,* 10(2), 297.
17. Gaikwad, S. B., Mane, S. P. & DK, D. B. (2019). Crop Combination Calculate Based on Weaver's Method in Malshiras Tahsil. *Research Journ.* Special Issue-133, Pp-301-306.
18. Gibbs, J. P., and Martin, W. T. (1962). Urbanization, technology, and the division of labor: International patterns. *Am Sociol Rev*, 667-677.
19. Husain., M. (2020). Agricultural geography. Rawat Publications.
20. Hydrogeological atlas of Rajasthan (2013). State ground water department Rajasthan.
21. Iqbal, C. (1979). High Yielding Varieties of Seeds and their Impact on Agricultural Development. book Dynamics of Agricultural Development in India, Concept Publications, New Delhi, India ,71-80.
22. Kar, A., 2014. Agricultural land use in arid Western Rajasthan: Resource exploitation and emerging issues. *Agropedology,* 24(2), pp.179-196.
23. Li, B., Liu, X., Zhu, D., Su, H., Guo, K., Sun, G., ... & Sun, L. (2023). Crop diversity promotes the recovery of fungal communities in saline-alkali areas of the Western Songnen Plain. *Frontiers in Microbiology*, 14.
24. Lyu, X., Peng, W., Yu, W., Xin, Z., Niu, S. & Qu, Y. (2021). Sustainable intensification to coordinate agricultural efficiency and environmental protection: A systematic review based on metrological visualization. *Journal of Land Use Science*, 16(3), 313-338.
25. Makate, C., Wang, R., Makate, M., and Mango, N. (2016). Crop diversification and livelihoods of smallholder farmers in Zimbabwe: adaptive management for environmental change. *Springer Plus*, 5(1),1-18.
26. Nemecek, T., Hayer, F., Bonnin, E., Carrouée, B., Schneider, A., & Vivier, C. (2015). Designing eco-efficient crop rotations using life cycle assessment of crop combinations. *European Journal of Agronomy*, 65, 40-51.
27. Nisha. (2015). Major Crop Combination Regions in Jammu Province: A Spatio-Temporal Analysis. *International Journal of Innovative Research in Science, Engineering and Technology*, 4(3), 897-905. doi:10.15680/IJIRSET.2015.0403014
28. Njeru, E. M. (2013). Crop diversification: a potential strategy to mitigate food insecurity by smallholders in sub-Saharan Africa. *Journal of Agriculture, Food Systems, and Community Development*, 3(4), 63-69.
29. Pawlak, K. & Kołodziejczak, M. (2020). The role of agriculture in ensuring food security in developing countries: Considerations in the context of the problem of sustainable food production. *Sustainability,* 12(13), 5488.
30. Piedra-Bonilla, E. B., da Cunha, D. A. & Braga, M. J. (2020). Climate variability and crop diversification in Brazil: An ordered probit analysis. *Journal of Cleaner Production,* 256, 120252.
31. Prasad, J. & Maravi, K. S. (2021). Geographical Study of Crop Combination and Crop Diversification in Dindori District, Madhya Pradesh, *The Deccan Geographer*, 59 (1 & 2), 118-132
32. Sapre, S.G. and Deshpande, V.D., (1964). Inter-district variations in agricultural efficiency in Maharashtra state. *Indian Journal of Agricultural Economics,* 19(902-2016-68160), pp.242-252.
33. Shafi, M. (2006). Agricultural geography. Dorling Kindersly (India) pvt, ltd, Licensees of Pearson Education in South Asia. New Delhi.
34. Tian, Z., Wang, J. W., Li, J. & Han, B. (2021). Designing future crops: challenges and strategies for sustainable agriculture. *The Plant Journal,* 105(5), 1165-1178.
35. Truscott, L., Aranda, D., Nagarajan, P., Tovignan, S., and Travaglini, A.L. (2009). A snapshot of crop diversification in organic cotton farms. Discussion paper. op diversification in organic cotton farms. Discussion paper, Soil Association, https://www.sustainabilityxchange.info/filesagri/Crop%20di versification.pdf (Available at: 01.09.2018).
36. Wang, G., Li, X., Xi, X. & Cong, W. F. (2022). Crop diversification reinforces soil microbiome functions and soil health. *Plant and Soil,* 476(1-2), 375-383.
37. Weaver, J. C. (1954). Crop-combination regions in the Middle West. *Geogr. Rev.,* 44(2) :175-200.
38. Wiebe, K., Lotze-Campen, H., Sands, R., Tabeau, A., van der Mensbrugghe, D., Biewald, A., ... & Willenbockel, D. (2015). Climate change impacts on agriculture in 2050 under a range of plausible socioeconomic and emissions scenarios. *Environmental Research Letters,* 10(8), 085010.
39. Yang, G., Li, S., Wang, H., & Wang, L. (2022). Study on agricultural cultivation development layout based on the matching characteristic of water and land resources in North China Plain. *Agricultural Water Management,* 259, 107272.
40. Zhang, P., Zhang, J., & Chen, M. (2017). Economic impacts of climate change on agriculture: The importance of additional climatic variables other than temperature and precipitation. *Journal of Environmental Economics and Management,* 83, 8-31.