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Transition in Cropping Patterns: Evidence from Bundelkhand Region of India

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ABSTRACT

Background: Bundelkhand region of India consist of 14 districts, evenly divided between southern Uttar Pradesh and northern Madhya Pradesh states representing 2.42% of India's total geographical area with a high percentage of barren and uncultivable land. The region is highly vulnerable and susceptible to climatic hazards. Wheat, chickpea sorghum, paddy, maize, barley, lentils, sesame, mustard, groundnut, soybean, peas and beans are the major crops grown in the region. In the context of climate change, noticeable shifts in cropping patterns have been observed. This study aims to analyse these patterns and assess the extent of change over time.

Methods: The dynamics of cropping patterns in the Bundelkhand region of India were analysed using secondary data collected from published reports of the Directorate of Economics and Statistics (DES), Government of India from a period to 2002-03 to 2021-22 (*i.e.* 20 years). The compound annual growth rate (CAGR) was employed to capture long-term growth trends. Furthermore, seasonal temporal changes in the cropping pattern of the region were captured by a Transition Probability Matrix (TPM).

Result: Results of the analysis indicated a significant change in the cropping pattern over the period, with kharif crops experiencing a strong growth at CAGR of 5.54%, rabi crops at CAGR 2.02% and substantial growth in pulse area at CAGR of 1.96%. Significant temporal shifts in cropping patterns during the kharif season were observed in the Bundelkhand region. Among the kharif crops, urdbean crop registered highest and significant CAGR of 10.90%. Similarly, area expansion under mungbean, pigeon pea, paddy, sesame, groundnut and soybean registered substantial area expansion, while the area under maize remained almost stagnant at 38 thousand ha over the period of time. Traditionally grown coarse cereals such as sorghum and small millets have witnessed a drastic reduction in area coverage in the region. The TPM analysis revealed the higher probability of area retention among cereal crops (wheat (0.89) and paddy (0.54) and pulse crops (urdbean (0.67), lentil (0.71), mungbean (0.55), chickpea (0.87) and field pea (0.70), while millets had a higher probability of losing their area. The government needs to promote climate-suitable crops to reduce water scarcity and related risks, which can ultimately lead to India's self-sufficiency in pulses in Bundelkhand region.

Key words: Area, CAGR, Crops, *Kharif*, *Rabi*, TPM.

INTRODUCTION

Bundelkhand region of India spans over 7.09 million hectares, representing 2.42% of India's total geographical area with a high percentage of barren and uncultivable land (Sharma and Srivastava, 2020). The region comprises 14 districts, evenly divided between southern Uttar Pradesh and northern Madhya Pradesh states. Agriculture and allied sectors are the primary livelihood of nearly 70% of the total inhabitants of the region (Garg *et al*., 2024). The region is marked by dominance of small and marginal farm holdings, accounting for approximately 75% of the total land holdings (Sharma and Srivastava, 2020), low to average annual household income (Tripathi, 2019), poor crop productivity (Shakeel *et al*., 2012, Palsaniya *et al*., 2008; Chavan *et al*., 2016; Singh and Bhanvi 2023) and a lack of access to modern farming techniques (Jatav and Nayak, 2021). This region is well known for peculiarities such as undulating topography (Kumar *et al*., 2021), threatened groundwater resources (Sah *et al*., 2024), erratic rainfall (Liansangpuii, 2024), heightened climatic vulnerability (Jatav and Bharti, 2023) and susceptibility to frequent drought (Palsaniya *et al*., 2008; Gupta *et al*., 2014; Sandhu *et al*., 2016; Ahmed *et al*., 2019, Prakash and Mishra, 2020), water scarcity (Suresh, 2019) and soil degradation (Prakash *et al*., 1998) and is particularly vulnerable to climate change (Prasad *et al*., 2012).

The gross cropped area of the region is 6.68 million ha with a cropping intensity of 163 per cent (author's calculation). Crops such as wheat, chickpea sorghum, paddy, maize, barley, lentils, sesame, mustard, groundnut, soybean, peas and beans are the dominant crops grown in this

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region (Sah *et al*., 2022). Bundelkhand is an important pulse growing region of the country that contributes about 10.3% (2.83 million ha) to total pulse area in the country with significant share in total area under field pea (49.76%), urdbean (24.90%), lentil (23.84%), pigeon pea (17.63%) and chickpea (7.95%) cultivation in the country (Directorate of Economics and Statistics, 2021-22). The region also contributes approximately 3.92 and 2.6 percentage of the total area under cereals and oilseeds in the country, respectively. The Bundelkhand region accounts for 9.38% of the total linseed production in the country.

As a climate vulnerable region of the country, the cropping patterns in Bundelkhand have undergone significant changes over time, with fluctuations in the area, production and productivity of crops (Sah *et al*., 2022). A positive change has been recorded in the cropping pattern of cereals, pulses, oilseeds and cash crops over the last 20 years (1994-95 to 2014-15) (Yadav, 2021).

Gaining insights into these changing cropping patterns is crucial for developing sustainable and climate-resilient agricultural strategies (Yadav *et al*., 2025). In this perspective, a temporal analysis of the pattern of change and shifting in area coverage in Bundelkhand region of India over the past two decades (2002-03 to 2021-22) has been analysed. More importantly, the change and shifting in the crop pattern is seasonal in nature, this has been analysed in relation to the main growing seasons *i.e. kharif* (rainy) and *rabi* (winter).

MATERIALS AND METHODS

The study was conducted in 14 districts of the Bundelkhand Region of India. *Kharif* (rainy) and *rabi* (winter) are the two major cropping seasons in the region. The *kharif* growing season extends from June to November, whereas the rabi season extends from November to March. The *rabi* crops included mustard, linseed, chickpea, lentil, field pea, barley, wheat and other *rabi* crops cultivated in very small areas were grouped under the category of 'other *rabi* crops'. The group of *kharif* crops included urdbean, pigeon pea, soybean, groundnut, sesame, rice, maize and sorghum and *kharif* crops covering smaller area have been group the 'other *kharif* crops' (Kumar *et al*., 2017).

The data on area coverage under kharif crops and rabi crops were collected from published reports of the Directorate of Economics and Statistics, Government of India from 2002-03 to 2021-22(20 years). The study was conducted at ICAR-IIPR, Kanpur during 2023-24. The seasonal growth trend of crops was analysed using the Compound Annual Growth Rate (CAGR) and to understand the extent of the shifting pattern, Markov analysis was used.

Compound annual growth rate (CAGR)

The compound annual growth rate (CAGR) was employed to capture long-term growth trends using the following exponential function (Maurya *et al*., 2016).

$$Y = AB^t$$

Where

Y = Variable for which the growth rate is calculated.

t = Time variable.

B = Regression coefficient.

A = Intercept.

The log form of the exponential equation above is expressed as

$$\log (Y) = \log (A) + \log (B)$$

Compound growth rate percentage (r %) can be expressed as:

$$r\ \% = [\text{Antilog} (\log B) - 1] * 100$$

The statistical significance of the growth rate was assessed using the student's *t*-test as

$$t = r/\text{s. e. } (r)$$

which follows a t-distribution with n-2 degree of freedom (Kumar *et al*. 2009).

Where

s.e. = Standard error.

'n' = Number of years confidence considered in the study.

$$\text{s.e. } (r) = [(100\times b)/0.43429] \times \text{s.e. log } (b).$$

Markov Chain modelling was used in this study to analyze the shifts in cropping patterns. and the process was represented using a Transition Probability Matrix (TPM) (Niu and Zhou, 2023). Several researchers have utilized this model to analyze crop shifting patterns (Toppo, 2024; Pazhanivelan, 2024; Saritha, 2023; Gayathri *et al*., 2023).

A transition matrix was computed using MS Excel and LPsolve. Computation of 'P' matrix representing transitional probability is the core component of Markov Chain Analysis. The P_{ij} entries of matrix P represent the likelihood that the area under one crop will eventually shift from the area under a specific crop *i* to the other crop *j*. The fundamental Markov model is expressed as follows:

$$E_{jt} = \sum_{i=1} E_{it-1} P_{ij} + e_{jt}$$

Where,

E_{jt} = Area shifting to the j^{th} crop in year t.

E_{it-1} = Area of the i^{th} crop in year t-1.

P_{ij} = Probability that the area will shift from the i^{th} to j^{th} crop.

e_{jt} = Error term that is statistically independent of.

t = Total number time periods considered for the analysis.

n = Total number of crops considered in the Markov analysis.

The transitional probabilities P_{ij} which can be arranged in an (n × n) matrix, have the following properties:

$$0 \le Pij \le 1$$

$E^n_{it-1} P_{ij} = 1$ for all *i* (Verma *et al*., 2024).

RESULTS AND DISCUSSION

The agriculture scenario in the Bundelkhand region of India witnessed a significant change in cropping patterns from 2002-03 to 2021-22. Temporal trends of overall area (ha)

under *kharif* crops over 20 years indicated a strong growth, from 1207.75 thousand hectares at TE 2002-03 to 2896.58 thousand hectares at TE 2021-22, recording an impressive CAGR of 5.54% (Fig 1). The figures translated to an absolute gain of 1689 thousand hectares under kharif crops, indicating an increase of 140 per cent during this period. However, the overall area coverage under kharif crops witnessed variability over the years, registering a sharp increase (46% to 52%) in years like 2003-04, 2010-11 and 2015-16 while notable decline to (-24.82%) in area was recorded in the year 2007-08 and 2009-10.

In contrast, the overall area under rabi crops in the Bundelkhand region showed a relatively moderate enhancement, with fewer interannual deviations. The area registered an increase from 3118.51 thousand hectares in TE 2002-03 to 3933.76 thousand hectares in TE 2021-22, marking an absolute gain of by 815.25 thousand hectares (26%) over the period (Fig 1). The area under rabi crops increased at CAGR of 2.02%. Although moderate growth was observed throughout the study period, an abrupt area enhancement of 1100 thousand hectares was recorded in 2016-17.

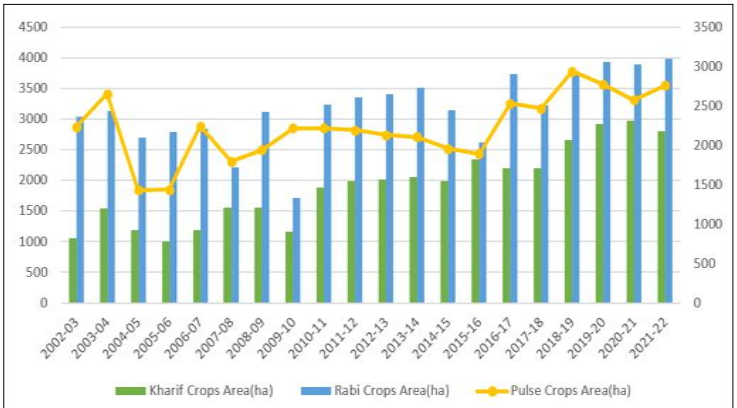
The periods of decline were prominent in 2007-08 and 2009-10. Despite having the greatest spatial coverage, the low growth rate of rabi pulses in the region indicates that these crops may reach saturation in terms of coverage area.

With regard to pulses, the total area under cultivation witnessed a modest but notable increase from 2112.63 thousand hectares at TE 2002-03 to 2700.76 thousand hectares at TE 2021-22, with an absolute increase of 588 thousand hectares in the region. This represents an enhancement of 27.83%, with CAGR of 1.96% (Fig 1). The area under total pulse crops in the region followed a fluctuating pattern, with two consecutive year from 2003-04 to 2005-06 witnessing a sharp decline in area, while from 2016-17 onwards a noticeable uptrend was witnessed.

The analysis indicates the dynamic nature of cropping patterns in the Bundelkhand region, with positive trends in overall area expansion under crops, which has significant implications for food security and farm income. Kharif crops have led to an expansion trend with the highest growth rate over the two decades in the region, which may be attributed to an increase in the availability of quality seeds of kharif crop availability of the right technological options in the region, which supported the conversion of kharif fallows into cultivation. The overall area under rabi crops also showed slight fluctuations, but remained relatively stable over the study period. Despite a slower growth in area coverage under pulses in relation to kharif crops and rabi crops, the sustained upward trend in pulse cultivation area suggests a growing emphasis on pulses in the region.

Temporal area shifts of rabi crops (2002-03 to 2021-22)

The cropping patterns of rabi crops in the Bundelkhand region have undergone prominent shifts over the past two decades (2002-03 to 2021-22). Among the rabi crops, wheat continued to be the predominant crop that registered



Year	Area under kharif crops (000 ha)	Area under rabi crops (000 ha)	Area pulse crops (000 ha)
TE 2002-03	1207.75	3118.51	2112.63
TE 2021-22	2896.58	3933.76	2700.76
CAGR%	5.54	2.02	1.96

Fig 1: Temporal trends in area coverage under crop groups (2002-03 to 2021-22).

Table 1: Area dynamics of rabi crops in Bundelkhand region of India.

	Wheat	Barley	Chickpea	Lentil	Field pea	Mustard	Linseed	Other *rabi* crops
TE 2002-03	1395.03	57.16	1102	229.59	177.70	50.62	56.74	0.56
TE 2021-22	2277.79	51.70	834.27	299.51	300.08	148.37	18.04	4.01
CAGR (%)	3.87**	-0.98**	-1.60**	2.10**	5.32**	5.43**	-5.37**	5.32**

** Significance level at 0.05%.

area expansion from 1395.03 to 2277.79 thousand hectares during the study period, with a statistically significant and positive CAGR of 3.87 percent (Table 1). In contrast, barley crops registered decline of 5.46 thousand hectares (CAGR -0.98%) during the same period. This steady expansion of the wheat area in the region over time reflects farmers' continued preference for wheat, supported by assured government procurement, stable yields, lower risk and access to improved seed varieties.

The area of pulse crops witnessed a mixed trend in the Bundelkhand region over the study period. Chickpea, the most important rabi pulse crop in terms of total area coverage, recorded absolute substantial decline in area of 267.73 thousand hectares from 1102 thousand hectares at TE 2002-03 to 834.27 thousand hectares at TE 2021-22 and accordingly registered a significant decline at CAGR of -1.60%. In contrast to chickpeas, the area coverage under field peas showed steep growth with statistically significant CAGR of 5.32%. The area coverage of field pea crops increased from 177.70 thousand hectares in TE 2002-03 to 300.78 thousand hectares in TE 2021-22. The area under lentil also registered moderate growth with CAGR of 2.10%, which was statistically significant, reflecting on relatively stable area coverage over the period. The surge witnessed in the field pea and lentil area during the period in the Bundelkhand region could be attributed to technological innovations, rising demand and availability of improved varieties offering better yields and corresponding better economic returns. The decreasing trend in area coverage under chickpeas reflects shifting farmer preference, lower yield level and profitability, leading to their substitution with higher-yielding and commercially viable crops. This decline has raised concerns regarding the sustainability and economic viability of traditional crops.

Among the oilseed crops, the area under mustard cultivation reached 148.37 thousand hectares at TE 2021-22 from 50.62 thousand hectares at TE 2002-03, recording a positive and statistically significant growth (5.43% CAGR). In contrast, linseed crop witnessed a sharp decline in area from 56.74 thousand hectares in TE 2002-03 to 18.04 thousand hectares in TE 2021-22, registering a statistically significant decline at CAGR of -5.37%. This substantial area expansion under mustard crops observed in the Bundelkhand region from 2002-03 to 2021-22 can be attributed to the expanding market demand for mustard oil in the country and the positive trend of market price.

The crop group of other rabi crops included minor crops, such as tobacco, guar and sun hemp. These crops, though occupying small area, showed a high growth rate (CAGR 5.32%), reflecting on their increasing role in crop diversification in the region.

The analysis reveals that over the past two decades, the Bundelkhand region has undergone gradual diversification within Rabi cropping. Although wheat and mustard have gained significant sowing area ground, chickpea has experienced a relative decline. The area increases under

Table 2: Area (Thousand Ha) dynamics of *kharif* crops in Bundelkhand region of India.

Year	Sesamum	Groundnut	Soyabean	Pigeon pea	Mung bean	Urd bean	Paddy	Maize	Pearl millet	Sorghum	Small millet	Other *kharif* crops
TE 2002-03	80.92	81.76	279.46	59.32	17.48	181.08	257.64	38.73	25.24	115.26	19.11	3.85
TE 2021-22	394.21	174.31	491.20	77.12	41.36	1165.58	365.67	38.55	31.56	79.64	0.22	37.15
absolute	313.28	92.55	211.74	17.80	23.88	984.50	108.03	-0.18	6.33	-35.61	-18.89	33.30
% increase	387.14	113.20	75.77	30.01	136.55	543.69	41.93	-0.46	25.06	-30.90	-98.83	864.86
CAGR	8.75**	5.25**	4.36**	5.23**	7.41**	10.9**	3.04**	-1.24**	1.04**	-4.2**	-20.99**	9.72**

** Significance level at 0.05%.

field pea and lentil crops reflect a definite shift toward pulses with favourable economic and ecological profiles. The decline in linseed and stagnation of barley raises concerns over the sustainability and economic viability of traditionally grown crops in the region.

Temporal area shifts of *kharif* crops (2002-03 to 2021-22)

Analysis of area coverage under *kharif* crops over two decades (2002-03 to 2021-22) has revealed significant temporal shifts in cropping patterns in the Bundelkhand region of India. The *kharif* season in the region was dominated by urdbean, pigeon pea, soybean, groundnut, sesame, paddy, maize and sorghum, which also occupied sizeable land coverage. The *kharif* crops occupying minor area were clubbed as "other *kharif* crops" group for analysis.

The results revealed that among the kharif pulse crops grown in the region, urdbean witnessed maximum increase in cultivated area from 181.08 thousand hectares at TE 2002-03 to 1165.58 thousand hectares at TE 2021-22, registering 543.69% growth with highest and significant CAGR of 10.90% (Table 2). In similar trend, the growth rate of area expansion under mungbean crops is also impressive (CAGR 7.41%), with absolute gain of 23.88 thousand hectares (136.55 % increase) during the 20 years study period. Furthermore, pigeon pea crops registered significant area expansion of about 30 per cent from 59.32 thousand hectares at TE 2002-03 to 77.12 thousand hectares at TE 2021-22, registering CAGR of 5.23%. The steep growth of the Urd bean area reflects the preference for shorter-duration, low-input pulse crops, with suitable market and related policy support.

Among the oilseed crops, sesame registered immense area expansion from 80.92 thousand hectares at TE 2002-03 to 394.21 thousand hectares at TE 2020-21 registering an absolute enhancement of 313.29 thousand hectares (387%) and statistically significant CAGR of 8.75%. Groundnut and soybean also registered a substantial absolute gain in area *i.e.*, 113.20 and 75.77 thousand hectares over the period, thereby registering a significant growth with CAGR of 5.25% and 4.36%, respectively. This trend reflects the diversification toward oilseed crops in the region that may be based on improved market returns, technological interventions and policy emphasizing oilseed self-sufficiency in the country.

Paddy, a dominant cereal crop in kharif season, continued area expansion from 257 to 365.67 thousand hectares from TE 2002-03 to TE 2021-22, with a growth at CAGR of 3.04%. The area under maize crop remained almost stagnant (CAGR -1.24%) at 38 thousand hectares over the period of time.

Traditionally grown coarse cereals like pearl millet, sorghum and small millets recorded a mixed growth rate, with pearl millet registering a minor increase from 25.24 to 31.56 thousand hectares with CAGR of 1.04%. The other two crops witnessed drastic reduction (31% to 99%%) in area coverage. In this context, sorghum recorded an absolute decline of almost 31 thousand hectares with negative and statistically significant decline at CAGR of -4.2%, while the area under small millet crops contracted from 19.11 to mere 0.22 thousand hectares (98.8% reduction), with CAGR of -20.99%, making the crops almost losing ground in the region over the study period. These declines in sorghum and small millets can be attributed to changing food preferences, leading to reduced market demand and increased irrigation facilities in this traditionally rainfed region. In contrast, the rising area under pearl millet may be due to the popularization of hybrids and the assured market in the form of the poultry and animal feed industries.

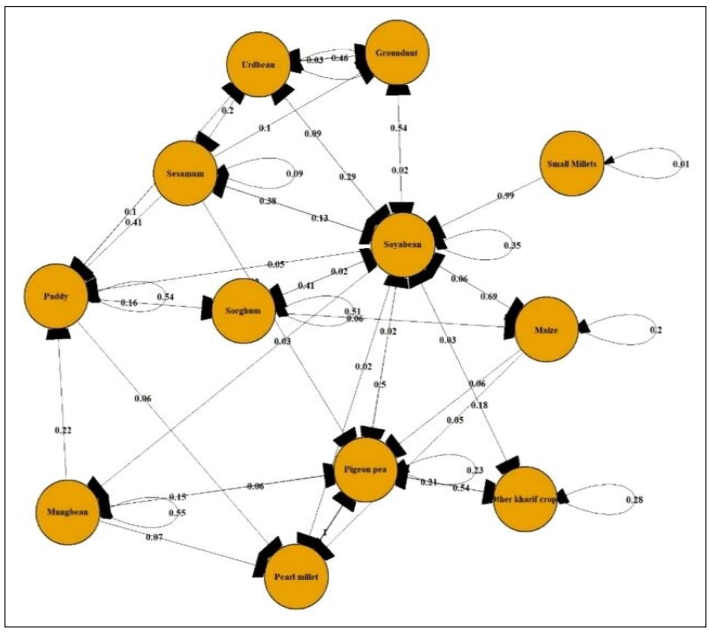


Fig 2: Directions of shift in area under major kharif crops in Bundelkhand region.

In contrast, the crop group of other kharif crops, that included cotton and sugarcane crops, registered a significant area expansion from 3.85 to 37.15 thousand hectares over the period, recording an absolute increase of 33.3 thousand hectares (864.86 % increase), with CAGR of 9.72% (Table 2). This trend possibly indicates an increased preference for cultivation owing to increased irrigation facilities and emerging markets for these crops in the region.

The overall results indicate a definite shifting trend of diversification from cereals and millets to pulses and oilseeds in the Bundelkhand region of the country. This pattern is in tune with the agroecological suitability of the region for the cultivation of these crops, as well as their market demands. These trends also highlight the need for appropriate research and policy support for the emerging cropping patterns in this region (Deshmukh *et al*., 2025).

Transition in area coverage under major kharif crops

The transitions in the cropping pattern of the Bundelkhand region from 2002-03 to 2021-22 were analyzed and captured using computation of a transition probability matrix (TPM). The separate TPM was calculated for *kharif* and *rabi* crops. The diagonal element of the TPM indicates the probability of area retention for a particular crop. The vertical and horizontal elements of the TPM show the probabilities of gaining and losing areas under a particular crop, respectively.

The data presented in Fig 2 indicates that the probability of area retention among kharif crops was higher for urdbean (0.67), mung bean (0.55), paddy (0.54) and sorghum (0.51). The area retentions of small millet (0.01), sesame (0.09), maize (0.20), pigeon pea (0.23) and other kharif crops (0.28) were lower.

Further, it can be observed that the ground nut lost its major area to soybean and urdbean, while pearl millet lost its entire area to the pigeon pea crop. Greater policy support for kharif pulses, such as pigeon pea and urdbean, coupled with favorable market prices, could be the reason for the shift in crop coverage.

The net gain in the probability of area retention was analyzed (Fleix and Ramappa, 2023) and was found to be positive for soybean, pigeon pea, urdbean and paddy in the region. Soybean emerged as the most prominent substitute kharif crop in the region and received significant area reallocation from small millets (0.99), maize (0.69), groundnut (0.54), pigeon pea (0.50), sorghum (0.41) and sesame (0.38).

In contrast, the probability of net gain from other crops was negative for millet (small millets, pearl millet, sorghum), oilseed crops (sesame and groundnut) and maize crops. This indicates a major structural shift in the kharif cropping system. The emergence of millets (small millets, sorghum and pearl millet) as unstable crops calls for concerted efforts for their promotion in the region owing to their nutritional importance for the people.

Transition in area coverage under major *rabi* crops

Among the rabi crops (Fig 3), the probability of area retention was higher for crops such as wheat (0.89), chickpea (0.87), lentil (0.71) and field pea (0.70). The area under wheat was further reinforced by a shift in the area share of other crops, such as mustard (0.98), chickpea (0.10) and field pea (0.03), making it very stable in the region. The area under the chickpea crop also appeared to be reinforced by linseed (0.46), field peas (0.23) and lentils (0.12). Notably, wheat, chickpea and field pea crops registered a positive net gain in the probability of area retention. Interestingly, the field pea and lentil crops appeared to have the probability of gaining area from chickpea, which reflects the competition among the pulse crops for area coverage.

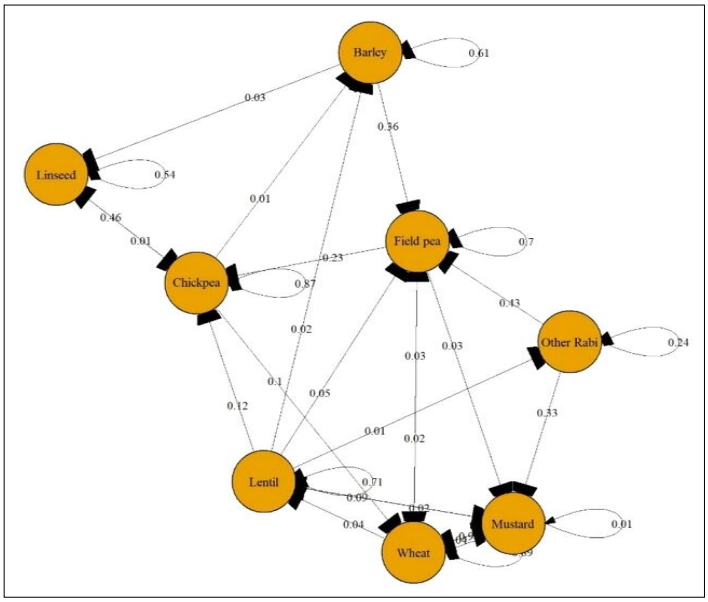


Fig 3: Directions of shift in area under major rabi crops in Bundelkhand region.

Although lentils and barley linseed had higher retention rates, their net gain in the probability of area shift from other crops was found to be negative. In the case of chickpeas (0.68) and field peas (0.56), the probability of net gain in area from other crops was found to be positive.

It can be concluded that wheat continued to dominate the *rabi* crop cropping scenario, with the probability of gaining area from mustard, chickpea and even linseed. Pulse crops, such as chickpeas and field peas, also maintained stability and gained from cereal and oilseed crops.

CONCLUSION

Bundelkhand is an important pulse-growing region in India that contributes to significant areas under pulse crops. Owing to a number of underlying factors, a significant change in the cropping pattern is observed in this region. Hence, the temporal shift in the areas of different crops has been significant in recent decades. CAGR and Markov analyses were utilized to study the trends and crop shifting patterns, respectively. All areas under the crops showed remarkable changes in the kharif season, with urdbean, mungbean and pigeon pea showing a high positive growth rate during the study period. However, modest growth has been observed in *rabi* pulse crops, such as field peas and lentils. This may be attributed to the changing food patterns, increased irrigation facilities and positive markets. Significant area growth under other rabi and kharif crops is reflected in minor crops, assuming a greater share in the cropping patterns. Markov analysis clearly indicated that urdbean and wheat crops were the most stable crops, retaining the maximum area in the kharif and rabi seasons, respectively. Furthermore, cereal crops (wheat and paddy) and pulse crops (urdbean, chickpea, field pea) had higher area retention rates in the region, whereas millets had a higher probability of losing their area.

Penetration of technological interventions are required to develop a roadmap for climate-resilient crop planning in the Bundelkhand region to maintain environmental sustainability. Policy measures should focus on ensuring quality seed availability to farmers and promoting crop diversification through intercropping, ridge farming and fallow-kharif cultivation as viable alternatives.

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Disclaimers

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Conflict of interest

We wish to confirm that there are no conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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