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Economic Evaluation of Crop Transition Patterns in Ananthapur District, Andhra Pradesh, India

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The study aims to examine the crop shifts in Anantapur district of Andhra Pradesh. Anantapur is the southern-most district of the Rayalseema region of Andhra Pradesh. While agriculture remains the most important economic activity of the district, it is characterized by high levels of instability and uncertainty. Being in the rain-shadow region of Andhra Pradesh, the district is drought-prone. The results revealed that the groundnut which is an important crop in the district recorded a negative and non-significant growth rate of 0.69 per cent in area, but the productivity and production were significant. The result of Markov chain analysis shown that groundnut was the most stable crop with high retention probability compared with other crops in the district. The crops from which groundnut gained were bengalgram, redgram, jowar, chillies and sunflower but with varying transfer probabilities. The area under paddy was significantly influenced by rainfall. The area of ragi, cotton and bengalgram were influenced by their own lagged prices.

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Keywords: Economic evaluation; crop transition patterns; groundnut; agricultural growth.

1. INTRODUCTION

The cropping pattern indicates the area under different crops grown in various seasons. It may differ for each holding in the same area and also from year to year on the same holding. The changes in cropping pattern in terms of absolute increase or decrease in area under specific crop over a period of time constitute crop shift. It often shifts from less profitable to more lucrative crops due to factors like technology, government policies, market infrastructure, and price incentives (Mohan,2017). There will be a time lag between improvement in technology and adjustment of cropping pattern. In general, there is a shift from traditionally grown less remunerative crops to more remunerative crops (Acharya et al., 2011). The crop shift can be a result of one or more of several reasons like government policies, thrust on some crops over a given time, market infrastructure development and certain other price related supports. The development took place in the country over the past five decades indicate that policy makers and planners are increasingly showing their concern towards agricultural diversification to promote agricultural growth and improve productivity through appropriate policies and fiscal support. Crop substitution and shift are also taking place according to availability of irrigation facilities (Kolay, 1993) and distinct soil problems like salinity, sodicity etc. Technological innovations have led to changes in cropping patterns (Kogo wt al., 2021), as farmers adopt new practices to increase income. Understanding these shifts is key for planning crop diversification or concentration. In recent years many technological innovations like development of high yielding varieties, use of chemical fertilizers, drought and disease tolerant varieties took place. Farmers are increasingly showing their interest to adopt these inventions for increasing their income and better standard of living. In this process many changes in the cropping pattern occurred. In this context an understanding of farmer's cropping pattern shifts assume importance in the contextual of planning for crop diversification or crop concentration.

Anantapur District is in an arid agro-ecological zone with dry summers and mild winters. The district's landscape includes hills (14%), undulating lands (27%), and gently sloping plains (54%). Valleys cover 5% of the area, influencing agriculture and water management The district lies between 13°40´ and 15°15´ North latitude and 76°51´ and 78°30´ East longitude. It shares common boundaries with Bellary, Kurnool districts on the East and North respectively, Kadapa and Kolar district of Karnataka on South and West respectively. The geographical location of the district is in such a way that it gets less rain creating agricultural conditions more unpredictable. The geographical area is 19,130 sq kms. Its Northern central portions are a high plateau, generally undulating with large granite rocks or low hill ranges. In the Southern portion of the district, the surface is hillier, the plateau there rising to 2600´ above the sea level. Generally, drought prone district, it receives an average annual rainfall of just 580 mm. It is known to be the second driest area in the country after Jaisalmer district of Rajasthan (Indian Meteorological department). The districts Agricuture is primarily rainfed with goundnut as the major crop. Food grain crops like paddy, jowar, maize, ragi, red gram, and Bengal gram also grown. Oilseeds like sunflower and commercial crops like cotton and chillies are cultivated. This aligns with studies emphasizing the impact of agro-climatic conditions on crop production (Davis et al., 2020; Lesk et al., 2016). Agriculture is the district's main economic activity, with 54.66% of the area under cultivation, and 72% of the cropped area is dedicated to groundnut, making it the highest producer in the state. Around 87% of the cropped area is rainfed.

2. METHODOLOGY

Data used for the study was collected from various published and unpublished sources. Time series secondary data on area, production and productivity of different crops, rainfall, wage rates, fertilizer prices, land utilization particulars, and other agricultural statistics were obtained from various "Statistical Abstracts" published by Directorate of Economics and Statistics, Government of Andhra Pradesh and from the Chief planning office of the district. The data covered a period of 30 years i.e., from 1992-93 to 2021-22.

The methods of analysis employed in the present study are:

1. Growth Model
2. Markov Chain Analysis
3. Multiple Regression Analysis

2.1 Growth Model

The growth in area, production, productivity of all the crops selected in all the four districts of Rayalaseema region and were analysed using the exponential growth function of the following form.

$Y = ab^t e$ ....

Where, Y = Dependent variable [Area (´000 ha.) / Production (´000 tonnes) / Productivity (q/ha)]
a = Intercept b = Regression coefficient t = Time variable e = Error term

The compound growth rates were obtained from the logarithmic form of the equation as below:

$$\ln Y = \ln a + t \ln b + e \qquad \text{.....(1)}$$

The per cent compound growth rate (CGR) was derived using the relationship. CGR = (Anti log b-1) x 100

2.2 Markov Chain Analysis

Markov chain analysis is a dynamic programming application used to solve stochastic decision processes, described by a finite number of states. This method was employed to study shifts in cropping patterns in Ananthapur district over the period 1992–93 to 2021–22, providing insights into the dynamics of these changes.(Kammar and Basavaraja, 2012).

2.3 Markov Probability Model

A stochastic process represents any sequence of trials (or experiments) subjected to probabilistic analysis. In such a process, transitions between states (outcomes) are governed by a probabilistic mechanism. A finite Markov process, a specific stochastic process, assumes that the outcome at trial t (where t=1,2,..,T) depends only on the outcome of the preceding trial (t−1), and this dependence remains constant throughout the sequence (Lee et al., 1965).

The components of a Markov process are defined as:

- Si: The i^{th} state or possible outcome (i=1,2,…,r).
- Wit: The probability that state Si occurs in trial t, represented as Pr(Sit).
- P_{ij}: The transitional probability denoting the likelihood of transitioning from state Si at time t to state Sj at t+1, represented as $Pr(S_{j,t+1}|Si,t) = Pij$.

The transition probability matrix P=[Pij], describing all possible transitions, adheres to the following properties:

1. $0<P_{ij}<1$
2. $\sum_j P_{ij}=1$ for i=1,2,…,r

The probability of transitioning from state Si at trial t to state Sj at trial t+1 is:

$$Pr(Sit,Sj,t+1)=Pr(Sit)\cdot Pr(Sj,t+1|Sit)=Wit\cdot Pij$$

The probability of being in state j at t+1 is expressed as:

$$Pr(Sj,t+1)=\sum_i Wit\cdot Pij$$

2.4 Data Characteristics

The analysis used data on land allocation to various crops, which fluctuates annually due to factors like weather, technology, market prices, and institutional changes. These variations are treated as a stochastic process. Crop shifts, depending on the crop type, are modeled using a first-order transition probability matrix P.

In the matrix Pij each element indicates the probability of transitioning from crop state *i* in one period to crop state *j* in the next. Diagonal elements P*ii* measure the likelihood of retaining a specific crop's area share.

2.5 Estimation of the Transition Probability Matrix

The statistical model for estimating transition probabilities incorporates errors to account for deviations between actual and estimated proportions. The model can be expressed as:

$$Wj,t+1=\sum_i Wi,t\ Pij + Uj,t,$$

or in matrix form:

$$Yj=XjPj+Uj$$

where:

- Yj: A T×1 vector of cropping pattern observations for crop j at time t.
- Xj: A T×r matrix of cropping pattern proportions for I at t−1.
- Pj: An r×1 vector of transition parameters to estimate.
- Uj: A vector of random disturbances.

2.6 Minimum Absolute Deviations (MAD) Estimator

To estimate parameters under equality or inequality constraints, the Minimum Absolute Deviations (MAD) method is applied. This approach minimizes deviations while ensuring non-negativity constraints for the transition probabilities.

2.7 Projection of Crop Shares

After estimating the transition probability matrix PPP, the future proportion of land allocated to different crops can be predicted using the equation:

$$Y'(t)=Y'(0)\cdot P^t$$

where:

- Y(t): A r×1 vector of crop proportions in year t.
- Y(0): A r×1 vector of crop proportions in the base year.
- P^t: The transition probability matrix raised to the power t.

This model provides a quantitative basis for understanding and forecasting the dynamics of cropping pattern changes in Ananthapur district.

2.8 Multiple Regression Analysis

To identify the factors influencing crop shifts in anantapur district of Rayalaseema region, multiple regression analysis was applied to the time series data for the period 1992-93 to 2021-22. The functional form used was of the following type.

Y = b0 + b1X1+ b2X2 + …….. + u ………………

where, Y = Area under the crop and X1, X2 …………. Xn are the explanatory variables.

b0 = Intercept; b1, b2,.………. bn = Regression coefficients.

u = Error term

3. RESULTS AND DISCUSSION

3.1 Growth Rates of area, Production and Productivity of Different Crops

Ananthapur District: The growth rates of area, production and productivity of different crops grown in the district *viz.,* paddy, jowar, maize, ragi, redgram, bengalgram, cotton, chillies, groundnut and sunflower are presented in Table 1 and in Figs. 1, 2 and 3 respectively.

Foodgrain Crops:

Paddy: Paddy productivity increased at an annual rate of 1.73 per cent, which was statistically significant 10 per cent level. The growth rates of area and production are significant and non-significant negative growth i.e -1.93 per cent and -0.24 per cent respectively.

Jowar: All the three parameters *viz.,* area, production and productivity registered negative significant growth rates of -3.60 per cent, -7.56 per cent and -4.10 per cent per annum respectively. The negative growth rate of area and productivity resulted in decline of production growth rate at -7.56 per cent.

Table 1. Compound growth rates of area, production and productivity of different crops in Ananthapur district (1992-93 to 2021-22) (per cent)

S.No.	Crops	Area	Production	productivity
		I.Foodgrain Crops		
1.	Rice	-1.937	-0.248	1.738
2.	Jowar	-3.601	-7.562	-4.107
3.	Maize	14.2259	16.8446	2.2933
4.	Ragi	-7.639	-8.401	-1.862
5.	Redgram	3.541	1.3891	-2.078
6.	Bengalgram	7.8311	7.9588	0.1183
		II.Non-Foodgrain Crops		
1.	Cotton	3.6237	1.7016	-1.855
2.	Chillies	-1.075	1.7601	2.8656
3.	Groundnut	-0.693	-4.606	-3.941
4.	Sunflower	-6.919	-7.906	-0.723

Note: *** denotes significance at 1% level.*
** denotes significance at 5% level.*
**** denotes significance at 10% level.*

Maize: Maize exhibited significant positive growth in area (14.22% per annum), production (16.84% per annum), and productivity (2.29% per annum). The combined impact of expanded cultivation and increased yield resulted in a substantial production growth rate of 16.84% annually.

Ragi: Ragi experienced a notable decline across all parameters, with negative growth rates in area (-7.63% per annum), productivity (-8.40% per annum), and production (-1.86% per annum). This consistent decrease highlights the crop's diminishing performance in the district.

Redgram: Redgram recorded growth in area (3.54% per annum) and production (1.38% per annum), though the production growth was statistically non-significant. A significant increase in area offset the negative growth rate in productivity, which declined at -2.07% per annum.

Bengalgram: Bengalgram production showed a significant positive growth rate of 7.95% per annum, driven primarily by a significant annual growth in area (7.83%). Productivity growth, although positive, was non-significant at 0.11% per annum.

Non-Foodgrain Crops:

Cotton: Cotton demonstrated significant positive growth in area (3.62% per annum) and production (1.70% per annum). However, its productivity showed a declining trend, with a negative growth rate of -1.85% per annum.

Chillies: Chillies showed significant positive growth in production (1.76% per annum) and productivity (2.86% per annum), despite a negative growth rate in area (-1.07% per annum).

Groundnut: Groundnut exhibited declining growth rates across all parameters, including area (-0.69% per annum, non-significant), production (-4.60% per annum, significant), and productivity (-3.94% per annum, significant).

Sunflower: Sunflower registered declining growth rates in area (-6.91% per annum) and production (-7.90% per annum). Productivity also declined at -0.72% per annum, but this trend was statistically non-significant.

The analysis reveals varying growth trends for key crops in Anantapur District. Maize and bengalgram have shown growth, while crops like ragi, groundnut, and sunflower have seen declines in most parameters.

These findings are consistent with studies on structural changes in cropping patterns in semi-arid regions (Pattanaik & Mohanty, 2017).

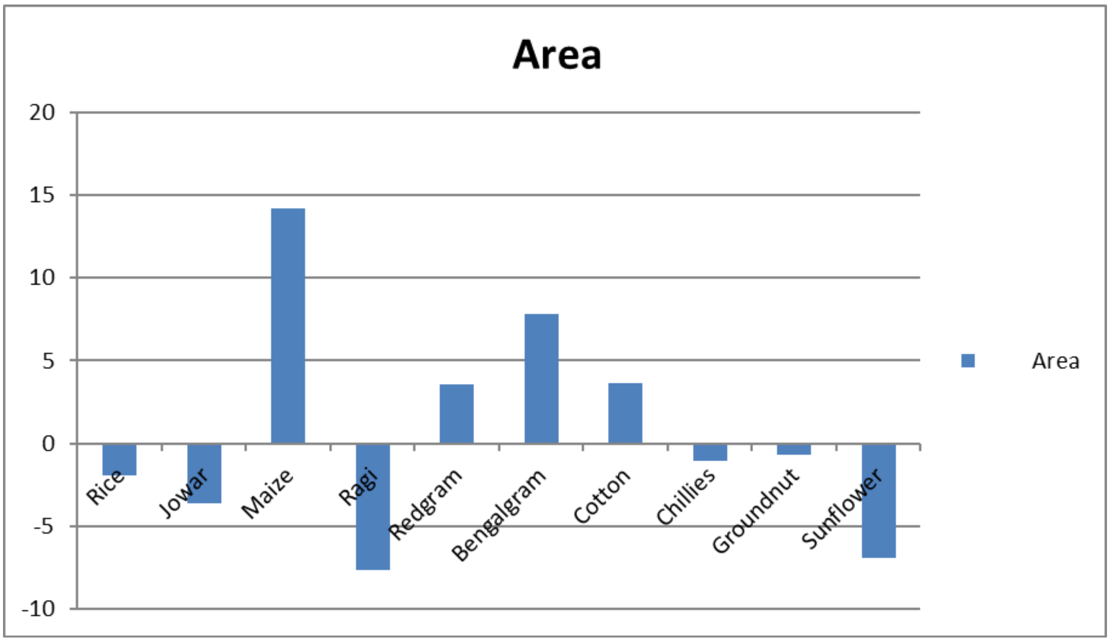

Fig. 1. Compound growth rates (%) of area under different crops in Ananthapur district (1992-93 to 2021-2022)

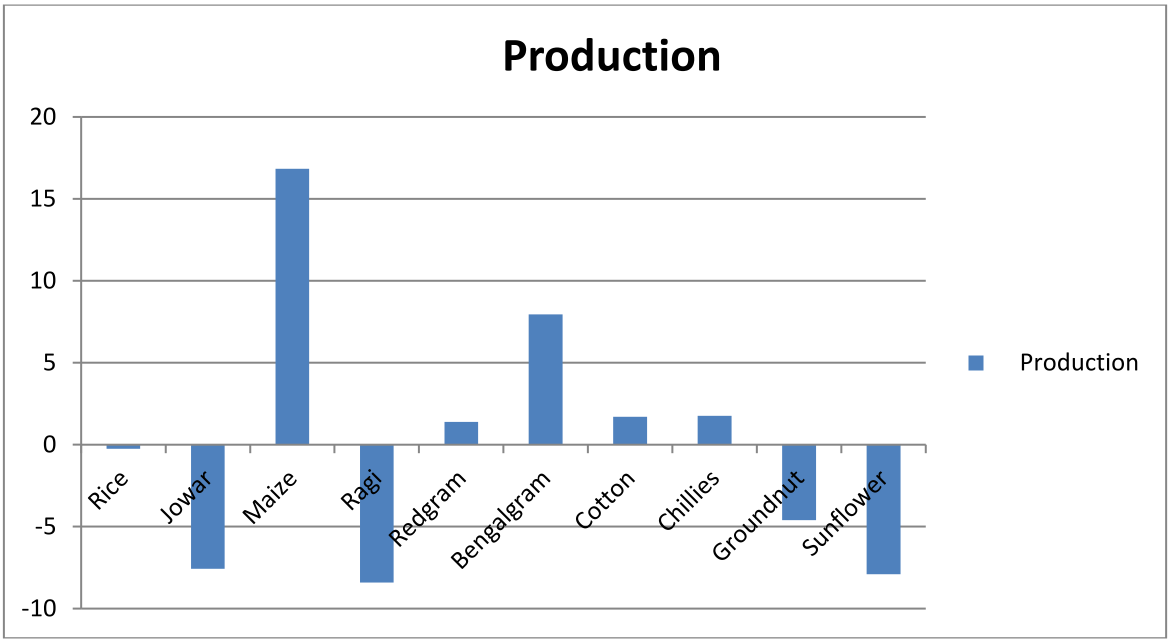

Fig. 2. Compound growth rates (%) of production under different crops in Ananthapur district (1992-93 to 2021-2022)

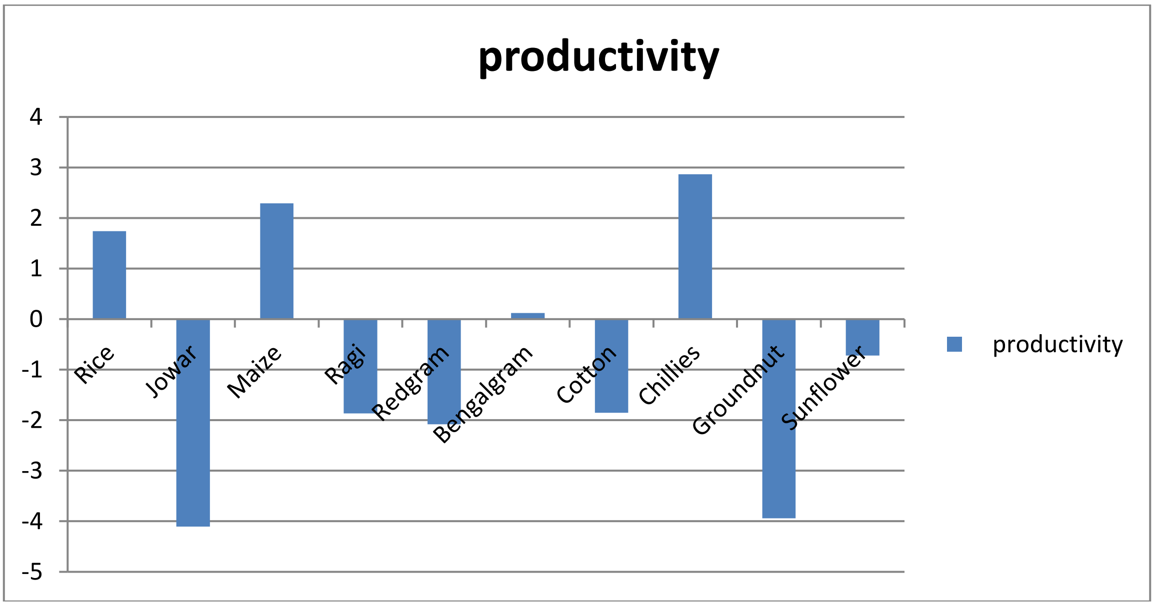

Fig. 3. Compound growth rates (%) of productivity under different crops in Ananthapur district (1992-93 to 2021-2022)

3.2 Direction of Cropping Pattern Changes

Transition Probability Matrix for Crops in Ananthapur District: The transition probability matrix in Table 2 illustrates the changes in the cultivation areas of various crops in the Ananthapur district. Among the crops analyzed, groundnut exhibited the highest retention probability, at 0.8737. This stability was further supported by gains from sorghum (0.9546), redgram (0.2195), bengalgram (0.5373), chillies (0.8186), and sunflower (0.8753). However, groundnut lost some area to paddy, sorghum, redgram, bengalgram, and sunflower, with transition probabilities of 0.0268, 0.0268, 0.0004, 0.0401, and 0.0319, respectively.

Cotton retained its cultivation area with a probability of 0.7737 but lost shares to redgram (0.0175), chillies (0.0340), and other crops (0.1747). Conversely, cotton gained shares from maize (0.1101) and redgram (0.0324).

Maize had a retention probability of 0.6708 and gained minor shares from redgram (0.0551) and bengalgram (0.0148). However, it lost a significant portion of its area to bengalgram (0.2189) and a smaller share to cotton (0.1101).

Ragi retained its area with a probability of 0.6379, losing only to sorghum (0.3620). It gained small shares from paddy (0.0296) and sorghum (0.0071).

Paddy displayed a retention probability of 0.5898, gaining a small share from groundnut (0.0268) but losing to ragi (0.0296), redgram (0.1034), chillies (0.0537), and sunflower (0.2232).

Redgram retained its area with a probability of 0.5316 but lost shares to maize (0.0551), bengalgram (0.0394), chillies (0.0018), cotton (0.0324), groundnut (0.2195), and other crops (0.1199). It gained area from paddy (0.1034), sorghum (0.0382), bengalgram (0.0556), chillies (0.1814), cotton (0.0175), groundnut (0.0004), and other crops (0.7885).

Bengalgram retained its area with a probability of 0.3727 and transferred shares to maize (0.0148), redgram (0.0556), groundnut (0.5373), and other crops (0.0195). It gained area from maize (0.2189), redgram (0.0394), groundnut (0.0401), and other crops (0.0662).

Other crops had a low retention probability of 0.1452, gaining shares from redgram (0.1199), bengalgram (0.0195), and cotton (0.1747), but losing significantly to redgram (0.7885) and bengalgram (0.0662).

Sunflower retained its area with a probability of 0.1246, losing a substantial share to groundnut (0.8753). It gained shares from paddy (0.2232) and groundnut (0.0319).

Chillies and sorghum were highly unstable, with no area retention. Chillies transferred most of their area to groundnut (0.8186) but gained shares from paddy (0.0573), redgram (0.0018), and cotton (0.0340). Sorghum similarly transferred most of its area to groundnut (0.9546) while gaining shares from ragi (0.3620) and groundnut (0.0268). These results align with Webber et al. (2018), who highlighted the role of crop stability in drought-prone regions.

Projection of Cropping Pattern: As per the projections in Table 3, the share of paddy in Anantapur District is expected to increase from 3.68% in 2021 to 4.01–4.61% by 2026. Jowar's share will decrease from 3.38% in 2021 to 1.92% in 2022 and 2.07% in 2026. Maize's share will decline from 1.95% in 2021 to 1.39% in 2026. Ragi's share will slightly increase from 0.25% in 2021 to 0.38% by 2026. Redgram's share is expected to decrease from 7.70% in 2021 to 5.12% in 2026, while Bengalgram will decrease from 7.46% to 5.69%. The share of chillies will decline from 0.54% to 0.33%, and cotton's share will decrease from 3.48% to 2.21%. Groundnut, the dominant crop, will increase its share from 68.37% in 2021 to 72.99% by 2026. Sunflower's share will rise from 0.42% in 2021 to 3.78% in 2026. The share of other crops is projected to decrease from 2.07% in 2021 to 1.41% in 2026. Overall, groundnut is expected to occupy nearly 72% of the gross cropped area by 2026, with most other crops retaining similar shares.

The projected share of paddy would range from 4.00 per cent in 2021-22 to 4.60 per cent in 2026-27. Similarly, the projected share of jowar ranged from 1.92 per cent to 2.07 per cent for the corresponding periods. The projected share of groundnut increased from 69.48 per cent in 2022-23 to 72.99 per cent in 2026-27. The shares of maize and other crops are reduced with minimum fluctuations. The shares of ragi and sunflower are slightly increased. The projected share of chillies is constant from 2022-23 to 2025-26 i.e. 0.33 per cent. The projected share of bengalgram is 5.69 per cent in 2025-26 against 6.44 per cent in 2022-23. The share of redgram would decline from 7.36 per cent in 2022-23 to 5.12 per cent in 2025-26. In respect of cotton the projected share for 2022-23 would be 3.16 per cent and would reduced to 2.21 per cent in 2026-2027.

3.3 Factors Influencing Cropping Pattern Changes in Ananthapur District

The influence of causal factors on acreage changes of important crops was analyzed and the results presented in Table 4.

Foodgrain Crops:

Paddy: The area under paddy was positively and significantly influenced by total rainfall and gross

Table 2. Transition probability matrix for shifts in cropping pattern in Ananthapur district(1992-93 to 2021-22)

Crops	Paddy	Jowar	Maize	Ragi	Redgram	Bengalgram	Chillies	Cotton	Groundnut	Sunflower	Other
Paddy	0.5898	0.0000	0.0000	0.0297	0.1035	0.0000	0.0537	0.0000	0.0000	0.2233	0.0000
Jowar	0.0000	0.0000	0.0000	0.0071	0.0382	0.0000	0.0000	0.0000	0.9546	0.0000	0.0000
Maize	0.0000	0.0000	0.6709	0.0000	0.0000	0.2190	0.0000	0.1101	0.0000	0.0000	0.0000
Ragi	0.0000	0.3620	0.0000	0.6380	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Redgram	0.0000	0.0000	0.0551	0.0000	0.5316	0.0395	0.0018	0.0324	0.2196	0.0000	0.1200
Bengalgram	0.0000	0.0000	0.0148	0.0000	0.0556	0.3728	0.0000	0.0000	0.5373	0.0000	0.0195
Chillies	0.0000	0.0000	0.0000	0.0000	0.1814	0.0000	0.0000	0.0000	0.8186	0.0000	0.0000
Cotton	0.0000	0.0000	0.0000	0.0000	0.0175	0.0000	0.0340	0.7738	0.0000	0.0000	0.1747
Groundnut	0.0269	0.0268	0.0000	0.0000	0.0005	0.0401	0.0000	0.0000	0.8737	0.0320	0.0000
Sunflower	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8754	0.1246	0.0000
Other	0.0000	0.0000	0.0000	0.0000	0.7885	0.0662	0.0000	0.0000	0.0000	0.0000	0.1452

Table 3. Actual and predicted proportions of area under major food and non-food crops in anantapuram district (1992-93 to 2026-27)

YEAR	PADDY		JOWAR		MAIZE		RAGI		GCA
	ACTUAL	PREDICTED	ACTUAL	PREDICTED	ACTUAL	PREDICTED	ACTUAL	PREDICTED	
1992	46693 (5.05)	47484.37 (5.14)	43120 (4.66)	24012.223 (2.60)	1263 (0.14)	2391.3163 (0.26)	11323 (1.22)	8916.746 (0.96)	924520
1993	49244 (5.28)	48676.399 (5.22)	49112 (5.27)	24013.908 (2.58)	1133 (0.12)	2291.6742 (0.25)	12190 (1.31)	9588.3393 (1.03)	931854
1994	36043 (4.06)	39699.516 (4.47)	38968 (4.39)	21720.041 (2.45)	1197 (0.13)	2597.7218 (0.29)	9137 (1.03)	7176.5938 (0.81)	888295
1995	41487 (4.45)	44461.442 (4.77)	31832 (3.42)	23205.939 (2.49)	2505 (0.27)	3441.3358 (0.37)	8964 (0.96)	7176.702 (0.77)	931708
1996	67411 (6.91)	60152.219 (6.17)	36477 (3.74)	23909.619 (2.45)	2976 (0.31)	3576.6932 (0.37)	9805 (1.01)	8515.2576 (0.87)	975579
1997	53607 (5.98)	49637.281 (5.54)	28905 (3.23)	20628.453 (2.30)	3385 (0.38)	3869.0439 (0.43)	7286 (0.81)	6444.6877 (0.72)	896030
1998	64989 (6.57)	59307.897 (5.99)	18478 (1.87)	23737.132 (2.40)	3592 (0.36)	4306.3851 (0.44)	7717 (0.78)	6982.738 (0.71)	989693
1999	58249 (6.18)	53599.764 (5.69)	32618 (3.46)	21729.079 (2.30)	3813 (0.40)	4235.1618 (0.45)	6949 (0.74)	6393.8738 (0.68)	942758

YEAR	PADDY		JOWAR		MAIZE		RAGI		GCA
	ACTUAL	PREDICTED	ACTUAL	PREDICTED	ACTUAL	PREDICTED	ACTUAL	PREDICTED	
2000	62004 (6.05)	58444.786 (5.70)	20313 (1.98)	24562.75 (2.39)	3874 (0.38)	4794.5623 (0.47)	7522 (0.73)	6782.911 (0.66)	1025693
2001	70997 (6.94)	62752.133 (6.13)	19070 (1.86)	22896.018 (2.24)	3114 (0.30)	4338.9615 (0.42)	5668 (0.55)	5857.9018 (0.57)	1022938
2002	40026 (4.07)	43741.003 (4.45)	15582 (1.58)	22119.831 (2.25)	4829 (0.49)	5887.1855 (0.60)	5574 (0.57)	4854.5113 (0.49)	983165
2003	28341 (3.01)	35135.806 (3.73)	33878 (3.60)	19827.704 (2.10)	7458 (0.79)	8035.3461 (0.85)	3967 (0.42)	3613.405 (0.38)	942169
2004	33575 (3.10)	43225.991 (3.99)	16171 (1.49)	24676.929 (2.28)	7067 (0.65)	7170.0191 (0.66)	3563 (0.33)	3384.4016 (0.31)	1084245
2005	48150 (4.30)	52540.1 (4.69)	16690 (1.49)	25107.819 (2.24)	7393 (0.66)	7616.9535 (0.68)	2775 (0.25)	3317.6216 (0.30)	1120010
2006	33195 (3.57)	37357.583 (4.02)	42987 (4.63)	18627.705 (2.00)	7997 (0.86)	8048.0731 (0.87)	2421 (0.26)	2836.0903 (0.31)	929417
2007	44492 (3.90)	50323.162 (4.41)	15648 (1.37)	24930.58 (2.18)	13488 (1.18)	12173.376 (1.07)	2449 (0.21)	2993.7085 (0.26)	1141447
2008	48722 (4.41)	52110.13 (4.72)	14283 (1.29)	23987.205 (2.17)	9699 (0.88)	9466.2219 (0.86)	1796 (0.16)	2692.7991 (0.24)	1104803
2009	51654 (6.169)	44708.394 (5.340)	59130 (7.062)	15501.818 (1.851)	13467 (1.608)	11544.906 (1.379)	3542 (0.423)	4214.0235 (0.503)	837299
2010	59801 (5.34)	57667.963 (5.15)	15880 (1.42)	23241.93 (2.08)	15476 (1.38)	15416.806 (1.38)	2432 (0.22)	3438.5378 (0.31)	1119279
2011	48668 (4.77)	48946.989 (4.80)	15097 (1.48)	21393.847 (2.10)	31655 (3.10)	25103.196 (2.46)	3269 (0.32)	3636.7728 (0.36)	1020621
2012	29054 (2.90)	36729.721 (3.67)	13394 (1.34)	20436.382 (2.04)	29109 (2.91)	23975.632 (2.39)	2412 (0.24)	2496.159 (0.25)	1001625
2013	40397 (3.91)	43386.766 (4.20)	21091 (2.04)	20571.284 (1.99)	34864 (3.37)	27411.849 (2.65)	2877 (0.28)	3184.2024 (0.31)	1033208
2014	29211 (3.64)	32420.368 (4.04)	18452 (2.30)	15844.814 (1.97)	21313 (2.65)	16708.06 (2.08)	1870 (0.23)	2191.1528 (0.27)	802845
2015	22887 (3.16)	26070.499 (3.60)	7090 (0.98)	13217.057 (1.83)	18306 (2.53)	15526.141 (2.15)	1837 (0.25)	1901.391 (0.26)	723456
2016	33575	43225.991	16171	24676.929	7067	7170.0191	3563	3384.4016	1084245

YEAR	PADDY		JOWAR		MAIZE		RAGI		GCA
	ACTUAL	PREDICTED	ACTUAL	PREDICTED	ACTUAL	PREDICTED	ACTUAL	PREDICTED	
	(3.10)	(3.99)	(1.49)	(2.28)	(0.65)	(0.66)	(0.33)	(0.31)	
2017	48150	52540.1	16690	25107.819	7393	7616.9535	2775	3317.6216	1120010
	(4.30)	(4.69)	(1.49)	(2.24)	(0.66)	(0.68)	(0.25)	(0.30)	
2018	33195	37357.583	42987	18627.705	7997	8048.0731	2421	2836.0903	929417
	(3.57)	(4.02)	(4.63)	(2.00)	(0.86)	(0.87)	(0.26)	(0.31)	
2019	44492	50323.162	15648	24930.58	13488	12173.376	2449	2993.7085	1141447
	(3.90)	(4.41)	(1.37)	(2.18)	(1.18)	(1.07)	(0.21)	(0.26)	
2020	48722	52110.13	14283	23987.205	9699	9466.2219	1796	2692.7991	1104803
	(4.41)	(4.72)	(1.29)	(2.17)	(0.88)	(0.86)	(0.16)	(0.24)	
2021	33623	36579.543	30837	17564.006	17843	16852.114	2325	2700.75	912257
	(3.69)	(4.01)	(3.38)	(1.93)	(1.96)	(1.85)	(0.25)	(0.30)	
2022		36579.543		17564.006		16852.114		2700.75	912257
		(4.01)		(1.93)		(1.85)		(0.30)	
2023		38596.046		17972.245		15879.983		2933.3494	912257
		(4.23)		(1.97)		(1.74)		(0.32)	
2024		40053.368		18323.96		14759.684		3144.4651	912257
		(4.39)		(2.01)		(1.62)		(0.34)	
2025		41153.358		18640.432		13679.697		3324.8869	912257
		(4.51)		(2.04)		(1.50)		(0.36)	
2026		41994.855		18898.139		12710.08		3474.8773	912257
		(4.60)		(2.07)		(1.39)		(0.38)	

YEAR	REDGRAM		BENGALGRAM		CHILLIES		COTTON		GCA
	ACTUAL	PREDICTED	ACTUAL	PREDICTED	ACTUAL	PREDICTED	ACTUAL	PREDICTED	
1992	26392	24189.386	6001	33550.03	3725	3038.409	14139	11935.51	924520
	(2.85)	(2.62)	(0.65)	(3.63)	(0.40)	(0.33)	(1.53)	(1.29)	
1993	24297	25579.667	12968	35699.82	4459	3038.533	10222	8822.394	931854
	(2.61)	(2.75)	(1.39)	(3.83)	(0.48)	(0.33)	(1.10)	(0.95)	
1994	23412	24079.786	34048	41749.38	2765	2262.712	8319	7328.257	888295
	(2.64)	(2.71)	(3.83)	(4.70)	(0.31)	(0.25)	(0.94)	(0.82)	
1995	26165	25314.863	21498	39804.09	1975	2698.254	12376	10700.79	931708
	(2.81)	(2.72)	(2.31)	(4.27)	(0.21)	(0.29)	(1.33)	(1.15)	
1996	25235	27980.985	12756	37246.01	4001	4051.238	11239	9842.729	975579

	(2.59)	(2.87)	(1.31)	(3.82)	(0.41)	(0.42)	(1.15)	(1.01)	
1997	21456 (2.39)	24875.535 (2.78)	28052 (3.13)	39333.61 (4.39)	3772 (0.42)	3168.512 (0.35)	7300 (0.81)	6717.324 (0.75)	896030
1998	27368 (2.77)	30475.219 (3.08)	26193 (2.65)	43470.59 (4.39)	4154 (0.42)	4018.477 (0.41)	13990 (1.41)	12108.4 (1.22)	989693
1999	23215 (2.46)	27447.382 (2.91)	26835 (2.85)	40938.22 (4.34)	5199 (0.55)	3494.407 (0.37)	9453 (1.00)	8487.442 (0.90)	942758
2000	30728 (3.00)	31676.579 (3.09)	33879 (3.30)	47813.69 (4.66)	3826 (0.37)	3797.367 (0.37)	12025 (1.17)	10728 (1.05)	1025693
2001	27947 (2.73)	32119.078 (3.14)	47910 (4.68)	51304.31 (5.02)	3873 (0.38)	4157.572 (0.41)	8552 (0.84)	7866.792 (0.77)	1022938
2002	33454 (3.40)	33532.561 (3.41)	54264 (5.52)	53296.31 (5.42)	2820 (0.29)	2471.948 (0.25)	7638 (0.78)	7527.099 (0.77)	983165
2003	41178 (4.37)	36345.586 (3.86)	51461 (5.46)	50522.58 (5.36)	3011 (0.32)	1741.53 (0.18)	4212 (0.45)	5416.289 (0.57)	942169
2004	32752 (3.02)	30878.281 (2.85)	42106 (3.88)	54047.61 (4.98)	3557 (0.33)	2167.972 (0.20)	8933 (0.82)	8752.847 (0.81)	1084245
2005	35013 (3.13)	33878.415 (3.02)	49105 (4.38)	57907.01 (5.17)	2236 (0.20)	2763.784 (0.25)	3295 (0.29)	4499.601 (0.40)	1120010
2006	26244 (2.82)	29782.155 (3.20)	83533 (8.99)	60965.73 (6.56)	1764 (0.19)	1883.188 (0.20)	1506 (0.16)	2897.402 (0.31)	929417
2007	36580 (3.20)	35201.239 (3.08)	74854 (6.56)	68769.49 (6.02)	2194 (0.19)	2576.699 (0.23)	3491 (0.31)	5373.391 (0.47)	1141447
2008	34067 (3.08)	34220.823 (3.10)	73055 (6.61)	66130.41 (5.99)	1574 (0.14)	2735.552 (0.25)	1611 (0.15)	3419.873 (0.31)	1104803
2009	20585 (2.459)	29539.52 (3.528)	92936 (11.099)	60139.37 (7.183)	1604 (0.192)	2883.917 (0.344)	2063 (0.246)	3747.281 (0.448)	837299
2010	66013 (5.90)	53866.25 (4.81)	94240 (8.42)	75107.04 (6.71)	1968 (0.18)	3480.317 (0.31)	4289 (0.38)	7164.585 (0.64)	1119279
2011	51745 (5.07)	47387.002 (4.64)	68483 (6.71)	65524.8 (6.42)	4165 (0.41)	3355.951 (0.33)	18997 (1.86)	19864.25 (1.95)	1020621
2012	56586 (5.65)	48339.616 (4.83)	89676 (8.95)	72038.75 (7.19)	2806 (0.28)	2604.521 (0.26)	27643 (2.76)	26430.86 (2.64)	1001625
2013	49932 (4.83)	49945.645 (4.83)	85768 (8.30)	71843.76 (6.95)	2674 (0.26)	3544.72 (0.34)	37723 (3.65)	34648.43 (3.35)	1033208

2014	37562 (4.68)	42700.86 (5.32)	22874 (2.85)	38703.31 (4.82)	2923 (0.36)	4175.244 (0.52)	74618 (9.29)	61302.77 (7.64)	802845
2015	38511 (5.32)	45807.75 (6.33)	75799 (10.48)	53967.13 (7.46)	3793 (0.52)	3366.876 (0.47)	60787 (8.40)	50300.4 (6.95)	723456
2016	32752 (3.02)	30878.281 (2.85)	42106 (3.88)	54047.61 (4.98)	3557 (0.33)	2167.972 (0.20)	8933 (0.82)	8752.847 (0.81)	1084245
2017	35013 (3.13)	33878.415 (3.02)	49105 (4.38)	57907.01 (5.17)	2236 (0.20)	2763.784 (0.25)	3295 (0.29)	4499.601 (0.40)	1120010
2018	26244 (2.82)	29782.155 (3.20)	83533 (8.99)	60965.73 (6.56)	1764 (0.19)	1883.188 (0.20)	1506 (0.16)	2897.402 (0.31)	929417
2019	36580 (3.20)	35201.239 (3.08)	74854 (6.56)	68769.49 (6.02)	2194 (0.19)	2576.699 (0.23)	3491 (0.31)	5373.391 (0.47)	1141447
2020	34067 (3.08)	34220.823 (3.10)	73055 (6.61)	66130.41 (5.99)	1574 (0.14)	2735.552 (0.25)	1611 (0.15)	3419.873 (0.31)	1104803
2021	70261 (7.70	67192.267 (7.37)	68092 (7.46)	58754.63 (6.44)	4966 (0.54)	3016.319 (0.33)	31799 (3.49)	28849.4 (3.16)	912257
2022		67192.267 (7.37)		58754.63 (6.44)		3016.319 (0.33)		28849.4 (3.16)	912257
2023		59724.047 (6.55)		54947.48 (6.02)		3069.352 (0.34)		26358.42 (2.89)	912257
2024		54212.028 (5.94)		53293.22 (5.84)		3079.428 (0.34)		24081.65 (2.64)	912257
2025		49990.499 (5.48)		52461.51 (5.75)		3070.3 (0.34)		22017.77 (2.41)	912257
2026		46737.887 (5.12)		51948 (5.69)		3051.558 (0.33)		20164.91 (2.21)	912257

YEAR	**GROUNDNUT**		**SUNFLOWER**		**OTHER CROPS**		**GCA**
	ACTUAL	**PREDICTED**	**ACTUAL**	**PREDICTED**	**ACTUAL**	**PREDICTED**	
1992	742749 (80.34)	725392 (78.46)	26488 (2.87)	37474.79 (4.05)	2627 (0.28)	6135.225 (0.66)	924520
1993	731105 (78.46)	730096.7 (78.35)	32513 (3.49)	38423.07 (4.12)	4611 (0.49)	5623.462 (0.60)	931854
1994	686769 (77.31)	700719 (78.88)	43136 (4.86)	35382.06 (3.98)	4501 (0.51)	5579.91 (0.63)	888295

1995	744528 (79.91)	730984.9 (78.46)	35593 (3.82)	37504.12 (4.03)	4785 (0.51)	6415.546 (0.69)	931708
1996	759419 (77.84)	749856.4 (76.86)	40927 (4.20)	44433.46 (4.55)	5333 (0.55)	6014.403 (0.62)	975579
1997	671047 (74.89)	694549.6 (77.51)	65985 (7.36)	41649.09 (4.65)	5235 (0.58)	5156.858 (0.58)	896030
1998	781179 (78.93)	754173.4 (76.20)	34842 (3.52)	43829.94 (4.43)	7191 (0.73)	7282.831 (0.74)	989693
1999	716650 (76.02)	727975.1 (77.22)	53573 (5.68)	42596.55 (4.52)	6204 (0.66)	5861.052 (0.62)	942758
2000	814607 (79.42)	786023.7 (76.63)	30606 (2.98)	43704.23 (4.26)	6309 (0.62)	7364.404 (0.72)	1025693
2001	777473 (76.00)	777744.5 (76.03)	51610 (5.05)	47142.95 (4.61)	6724 (0.66)	6757.837 (0.66)	1022938
2002	749791 (76.26)	761612.4 (77.47)	60319 (6.14)	40428.09 (4.11)	8868 (0.90)	7694.071 (0.78)	983165
2003	685995 (72.81)	736118.6 (78.13)	74525 (7.91)	37549.99 (3.99)	8143 (0.86)	7862.161 (0.83)	942169
2004	872323 (80.45)	860089.1 (79.33)	56819 (5.24)	42469.09 (3.92)	7379 (0.68)	7382.792 (0.68)	1084245
2005	899035 (80.27)	879972.6 (78.57)	48677 (4.35)	45562.65 (4.07)	7641 (0.68)	6843.476 (0.61)	1120010
2006	662111 (71.24)	724821.9 (77.99)	60751 (6.54)	36153.35 (3.89)	6908 (0.74)	6043.839 (0.65)	929417
2007	896826 (78.57)	887485.6 (77.75)	44442 (3.89)	44147.39 (3.87)	6983 (0.61)	7472.317 (0.65)	1141447
2008	870456 (78.79)	859213 (77.77)	42268 (3.83)	43977.79 (3.98)	7272 (0.66)	6849.23 (0.62)	1104803
2009	530381 (63.344)	624029.4 (74.529)	55286 (6.603)	35382.04 (4.226)	6651 (0.794)	5608.307 (0.670)	837299
2010	834070 (74.52)	826084.9 (73.81)	17615 (1.57)	42215.38 (3.77)	7495 (0.67)	11595.24 (1.04)	1119279
2011	753836 (73.86)	736262.2 (72.14)	13277 (1.30)	36623.59 (3.59)	11429 (1.12)	12522.36 (1.23)	1020621
2012	729695	722520.4	10580	31136.11	10670	14916.91	1001625

	(72.85)	(72.13)	(1.06)	(3.11)	(1.07)	(1.49)	
2013	728448	728121.1	14020	34057.71	15414	16492.56	1033208
	(70.50)	(70.47)	(1.36)	(3.30)	(1.49)	(1.60)	
2014	565751	542266	8452	25664.24	19819	20868.2	802845
	(70.47)	(67.54)	(1.05)	(3.20)	(2.47)	(2.60)	
2015	468183	472795.9	5331	20743.7	20932	19759.17	723456
	(64.71)	(65.35)	(0.74)	(2.87)	(2.89)	(2.73)	
2016	872323	860089.1	56819	42469.09	7379	7382.792	1084245
	(80.45)	(79.33)	(5.24)	(3.92)	(0.68)	(0.68)	
2017	899035	879972.6	48677	45562.65	7641	6843.476	1120010
	(80.27)	(78.57)	(4.35)	(4.07)	(0.68)	(0.61)	
2018	662111	724821.9	60751	36153.35	6908	6043.839	929417
	(71.24)	(77.99)	(6.54)	(3.89)	(0.74)	(0.65)	
2019	896826	887485.6	44442	44147.39	6983	7472.317	1141447
	(78.57)	(77.75)	(3.89)	(3.87)	(0.61)	(0.65)	
2020	870456	859213	42268	43977.79	7272	6849.23	1104803
	(78.79)	(77.77)	(3.83)	(3.98)	(0.66)	(0.62)	
2021	623732	633885.4	3868	27931.79	24911	18930.76	912257
	(68.37)	(69.49)	(0.42)	(3.06)	(2.73)	(2.08)	
2022		633885.4		27931.79		18930.76	912257
		(69.49)		(3.06)		(2.08)	
2023		643863.4		31915.95		16996.7	912257
		(70.58)		(3.50)		(1.86)	
2024		652817		33181.82		15310.4	912257
		(71.56)		(3.64)		(1.68)	
2025		659993.1		33951.26		13974.17	912257
		(72.35)		(3.72)		(1.53)	
2026		665857.6		34522.21		12896.83	912257
		(72.99)		(3.78)		(1.41)	

Table 4. Factors influencing area changes in major crops in Ananthapur district

S. No.	Crop	Intercept	regression coefficients						R^2
			price of the crop lagged by one year (x_1)	price of the competing crop lagged by one year (x_2)	total rainfall (x_3)	gross cropped area (x_4)	labour wage rate (x_5)	composite fertilizer price (x_6)	
I.Foodgrain crops									
1.	Paddy	0.982	0.089	0.089	0.557	1.300	-0.129	-0.301	0.5909
2.	Sorghum	12.521	-0.061	0.099	-0.505	0.549	-0.237	-0.387	0.3545
3.	Ragi	7.378	-0.882	-0.628	0.187	1.651	0.379	0.090	0.8229
4.	Redgram	10.950	0.105	-0.316	0.053	-0.302	0.522	-0.045	0.5924
5.	Bengalgram	10.037	1.963	-0.249	-0.225	-1.595	-0.197	-0.573	0.7118
II. Non-Foodgrain crops									
1.	Groundnut	13.407	0.275	-0.144	0.108	-0.144	-0.132	-0.081	0.3649
2.	Cotton	-22.598	0.456	-0.748	0.444	4.516	0.341	1.787	0.5156

irrigated area, while composite fertilizer price had a negative and significant impact. Labour wage rate was negative but non-significant, and both own lagged price and lagged price of the competing crop were positive but non-significant. The R^2 was 0.590.

Ragi: Gross irrigated area significantly and positively influenced the area under ragi, while own lagged price and lagged price of the competing crop had significantly negative effects. Total rainfall, labour wage rate, and composite fertilizer price were positive but non-significant. The R^2 was 0.822.

Redgram: The only significant factor for redgram was labour wage rate, which had a positive influence. Other variables, including lagged price of the competing crop, gross irrigated area, and composite fertilizer price, were non-significant, with negative signs. Own lagged price and total rainfall showed positive, but non-significant effects. The R^2 was 0.592.

Bengalgram: The variable which exhibited significant influence positively on bengalgram area was its own lagged price. All other remaining variables were negative and non-significant. R^2 was 0.711.

Non-Foodgrain Crops:

Groundnut: For groundnut, total rainfall was the only factor that significantly influenced the area under cultivation. The own lagged price had a positive but non-significant effect, while the lagged price of the competing crop did not significantly influence the area. The remaining variables were negative and non-significant. The R^2 was 0.364.

Cotton: The variables that were positively significant for cotton area were composite fertilizer price and gross irrigated area. Lagged price of the competing crop was negative and non-significant. Rainfall, own lagged price and labour wage rate were positive and non-significant. R^2 was 0.515.

The findings revealed that the area under ragi and bengalgram was influenced by their own lagged prices (Zebel et al., 2019), while lagged prices of competing crops negatively impacted ragi. Cotton was found to be a competing crop for paddy, bengalgram competed with ragi, and ragi competed with bengalgram. Sunflower was a competing crop for both redgram and cotton, while redgram competed with groundnut. Rainfall had a significant positive effect on the areas of paddy and groundnut. An increase in gross irrigated area positively influenced the areas under paddy, ragi, and groundnut. The area under redgram was positively influenced by the labour wage rate. The price of composite fertilizers had a negative significant impact on the area under paddy and a positive significant impact on the area under cotton.

4. SUMMARY AND CONCLUSION

The highest area growth rate was observed for maize, followed by bengalgram, cotton, and redgram. The highest productivity growth rate was for chillies (2.86%), followed by maize (2.29%) and paddy (1.73%). Area, production, and productivity exhibited negative and non-significant growth rates for jowar, while maize showed a positive and significant growth rate. Sunflower experienced negative and non-significant productivity growth, while bengalgram showed positive but non-significant productivity growth.

Retention and Transition Probabilities: Groundnut had the highest retention probability at 0.8737, primarily gaining area from sorghum, sunflower, chillies, bengalgram, and redgram. Cotton retained 0.7737, losing area to chillies and redgram but gaining from maize and redgram. Maize had a retention of 0.6708, gaining marginally from redgram and bengalgram, but losing to bengalgram (0.2189) and cotton (0.1101). Ragi had a retention probability of 0.6379, with major losses to sorghum (0.3620) and small gains from paddy (0.0296) and sorghum (0.0071). Paddy retained 0.5898, with minor gains from groundnut (0.0268) but losses to sunflower (0.2232), redgram, chillies, and ragi. Redgram had a retention of 0.5316, with significant gains from other crops, chillies, paddy, bengalgram, and sorghum. Other crops had a low retention of 0.1452, losing shares mainly to redgram and bengalgram. Sunflower retained 0.1246, losing significantly to groundnut but gaining from paddy and groundnut. Chillies and sorghum were highly unstable, with major transitions to groundnut

Crop Share Projections (2021 to 2026): Paddy increase from 3.68% to 4.61%. Sorghum declined from 3.38% to 2.07%. Maize drop from 1.95% to 1.39% Ragi shown slight growth from

0.25% to 0.38%. Redgram declined from 7.70% to 5.12%. Bengalgram reduced from 7.46% to 5.69%. Chillies relatively stable around 0.33%–0.54%.Cotton declined from 3.48% to 2.21% .Groundnut has growth from 68.37% (2016) to 72.99%. Sunflower has significant rise from 0.42% to 3.78%. Other Crops decline from 2.73% to 1.41%.

Factors Influencing Cropping Patterns: Lagged prices positively influenced ragi, bengalgram, and cotton, while negatively affecting other crops. Rainfall significantly boosted paddy, and irrigation expansion benefited ragi. Lagged production positively impacted paddy and cotton. Fertilizer costs hurt most crops except ragi. Groundnut, sorghum, and redgram competed with several crops.

Key Observations and Recommendations:

1. Decision-Driven Patterns: Changes in cropping patterns reflect farmers' choices influenced by socio-economic and climatic factors.
2. Commercialization: A shift toward non-foodgrain crops in dryland agriculture emphasizes the need for higher productivity and management efficiency.
3. Irrigation Influence: The Pattiseema Project is likely to promote high-value crops, potentially reducing coarse grains and millets.
4. Location-Specific Research: Given agro-climatic diversity, tailored agricultural technologies should be prioritized over uniform solutions.(Mahendra, 2010; Paramasivam et al., 2017)

This analysis highlights the need for integrating scientific research with farmers' practical challenges to enhance agricultural sustainability and efficiency.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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