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UNDERSTANDING THE PRODUCTION BEHAVIOR OF INDIAN SPICES: A STUDY OF CORIANDER AND CUMIN

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Abstract: Diversification of agriculture to less water demanding horticultural crops with commercial potentials can help in making sustainable use of land in resource-scarce regions, in enhancing farm income and in promoting food processing. Exercises with data on two seed spices grown in three western Indian states that contain exclusive agro-ecological features amenable for the crops indicate a rise of the crops coriander and cumin in states Madhya Pradesh and Gujarat respectively and a stagnation in Rajasthan, a state which has been long recognized for its natural advantage for producing these crops. The results also suggest significant effects of both economic and weather parameters on production. Water variable, as captured by rainfall, has a wide spatio-temporal dimension depending on interventions, hydrology and water management. Rainfall in pre-monsoon, monsoon and post-monsoon seasons not only in and around the states but notably, in the mountains have critical implications for sowing and yield performances while the winter weather effect on the crops come from local temperature and rainfall only in proximate regions.

Keywords: Spice production, rainfall effect, econometric modeling, Price response, commercialization of farming

1. INTRODUCTION

Spices have always been important components of the diet, cuisine and nutrition of the Indian people and for centuries they have also drawn consumer interest in the west but their entitlement to policy attention was limited. With the attainment of cereal sufficiency and the encroachment of urbanization into limited land use spaces, the horticultural sector started becoming increasingly commercialized drawing policy attention. With their flavor and aroma, spices make other food edible both in cuisines and food products. Science and experiences are revealing that many of the spices have special desirable properties for health. Growing spices generates marketing and food processing potentials when India is embarked on a determined path towards developing the rural economy by way of value addition, reforms and exports. Moreover, with their low demands for nutrients and water, growing seed spices can generate farm income from sustainable agriculture in arid regions.

Most spices have very exclusive agro-ecological requirements, but the varied region-specific geographic conditions give India a strong potential to grow spices for domestic and international markets. It is therefore important to understand the causal factors driving the decisions of planting acreage and allocating resources to these crops as well as the role of spatio-temporal rainfall dimensions to form an outlook of their production in a timely way and to monitor their production levels. Early estimates of production facilitate strategies to stabilize prices in the interest of the producers, traders, exporters and consumers of India and to organize intermediate and logistic processes for transport, storage, processing, packing and international transactions.

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The research is based on secondary official data from agriculture and weather for the period following 2000-01 till the latest (DES, Website, IMD, Website) and a dynamic model that estimates econometric regression equations blending economic, policy and climatic variables using contemporary period 2000-01 to 2017-18 as sample for which final production data is as yet reported officially. This paper focuses on two major seed spice crops cumin (jeera) and coriander (dhania) of Indian horticulture in two top growing states and attempts at analyzing the direction of performance and at modelling their acreage and yield assessing the model with validation and in the process, identifying the natural, economic and policy factors that are causal to their production.

2. BACKGROUND: CORIANDER AND CUMIN SEED CULTIVATION IN INDIA

Coriander and Cumin seeds are foremost among seed spices which also include fenugreek, fennel, ajwain, dill, anise, nigella, caraway and celery. Low in volume but high in value, they are grown traditionally in semiarid and arid parts of Rajasthan and Gujarat states that are well known as the "bowl of seed spices" (Lal, 2018), while the fringe of Madhya Pradesh close to the traditional growing districts, is quite successfully also joining the league. In whole or ground forms, they are nearly essential spices in Indian cuisines as well as in Mexican and Middle-eastern dishes, but around the world they are also used for such other purposes as condiments for sausages, confectionary, diary and preserves, brewing liquors, medicinal inputs, poultry feed and inputs for cosmetics. Enriched with minerals, vitamins and antioxidants they are gaining recognition for their health benefits.

2.1. Location, Agronomic demands and Developments

Though coriander is a native wild plant from southern Europe and northern Africa and cumin is originally from Egypt they are grown in India and around the world posing competition to India's exports. India's large production was earlier only consumed domestically but from 1970s exports of coriander seeds to different countries began. Other major coriander producers are Morocco, Canada, Pakistan, Romania and the former Soviet Union and possibly Eastern Europe (MoFA, Website). India exported 41.24 thousand tonnes of coriander seeds in the year 2018-19. Malaysia, UAE, UK, Saudi Arabia, South Africa are importers but the international demand is now increasing driven by heath awareness and globalization of tastes. Canadian coriander which is more uniform in size with good seed quality is a strong competitor in the export market. The major countries that produce cumin seeds are India, Turkey, Syria, Iran and China. India is the biggest producer of Cumin Seeds but the producers Syria, Turkey and Iran have significant influence in the determination of world jeera prices. In the recent past, Indian seed spices cultivation and export have been on the rise in spite of global recession.

Belonging to the Apiaceae family, both annual herbs thrive in special conditions where the weather is cool and dry, moisture is adequate but not excess and the soil is well drained and loamy. They both call for organic soil enriched with manures though they also need chemicals for improving yield (Yimam *et al*, 2015). Both crops are liable to wilting and are highly vulnerable to weeds and various pests like aphids and powdery mildew and predatory insects (leaf eating caterpillars, parasitoid wasps, ladybird beetles and semi-loopers) which can be pronounced by moisture in the air and soil, but the fragrance of the plants may also draw friendly insects that can check the harmful pests. Frosts, heavy rains, waterlogging, cloudy skies, humidity are restraints to their cultivation while cool sowing period, warm harvesting season, sunshine, controlled watering and well prepared flat land favour the crops (SBI, Website). Regulated irrigation, pest control, weeding, drying and post-harvest operations are crucial functions involved in successfully raising coriander and cumin for commercial use. Timely harvesting helps to avoid seed losses, after which the produce is winnowed, cleaned and dried in partial shade and stored in paper-lined gunny bags.

Thin stemmed with many branches, the coriander plant is small reaching a height of just

25 to 50 cm and has two distinct morphological types, one erect and the other bushy. Coriander is grown not only for its seeds but also for its vitamin rich leaves which add flavor to salads and Indian cuisines. Coriander is grown as a rabi season crop in the north and central parts of India with sowing being done between middle of October and middle of November. In some regions, such as in Tamilnadu, it is also grown as a kharif or a late kharif crops. It takes approximately 100 days for maturity though harvesting for green leaves starts earlier. For the purpose of seed, the rabi crop is ready for harvesting by April. Coriander performs well at a temperature range of 20 – 25 °C. The cumin plant grows taller at 30–50 cm height, having a uniform canopy with a slender and branched stem, each branch having two to three sub-branches. Cumin is a drought-tolerant plant ideal for Mediterranean climate but grows also in tropical or subtropical conditions. Indian growth season lasts 100 to 120 days. The optimum growth temperature ranges between 25 and 30 °C.

Spices are of great significance to India which is the largest producer and consumer and a major exporter in the world, fueled by a number of innovations. Pests and weeds are dominant constraints to their cultivation but identification of cumin blight-causing organism, research on the extent of cross-pollination and inheritance have been major breakthroughs. Integrated nutrient management and sowing of crops as per soil suitability with soil testing protocols have been serious factors for India's success. ICAR institutes, specialized in spices (IISR, Website, NRCSP, Website), engineered the pioneering development of a number of high yielding varieties and production technologies. AICRP-Spices is also conducting location and situation specific research on seed spices at its centers (Uppal *et al*., 1938, Prasad and Patel, 1963 and Ramanujam & Tewari, 1966).

2.2. Water Sensitivity and nutrition

Coriander and cumin are highly sensitive to water applied and the mode of irrigation has therefore been of research interest (Singh, 2014, Sharma *et al*., 2014, Kateshiya, 2020, Malhotra *et al*., 2009). Though water requirements of cumin are lower than many other species, it is often irrigated after sowing to be sure that enough moisture is available for seedling development but the amount and frequency of irrigation required depend on the climate conditions and the nature of soil. Moisture availability also affects the intake of different nutrients for higher yield, determines the growth of pests and causes wilting. Micro-irrigation technology makes cultivation secure while also saving water. Experiments have shown the advantage of resource conserving technologies that use groundwater or surface water with drip and sprinkler methods as against flooding and rainfall for watering. However, high cost has limited their use. Fertigation with drip irrigation is also seen as potential agronomic intervention that can significantly enhance productivity (Mehriya *et al*., 2020). Over and above 10-15 Kg of well rotten farmyard manure 20 kg nitrogen, 30 kg Phosphorus, and 20 kg Potassium per hectare are fertilizers in demand for coriander in rainfed areas but nitrogen requirement increases with irrigation (Bairwa *et al*., 2017). Certain soils also require other nutrients like zinc and Sulphur for growing spices.

2.3. Location and dynamics of cultivation in India

Figure 1 shows that at the end of the second decade of the century, the two top states growing Coriander and Cumin are respectively Madhya Pradesh (MP) and Rajasthan (RJ) and Gujarat (GJ) and Rajasthan, RJ being common among the leading states in both cases. Coriander is grown around the country also outside MP and RJ. State GJ, comes third, accounting for 16% of national coriander production in the three years ending 2017-18, but cumin is more concentrated, together, the two top states account for over 90% of its production in India compared to a little less than 70% in the case of coriander. Between the two top states, productivity is highly disparate in cumin. With 62% of the area, RJ accounts for only 42% of cumin production compared to 37% and 51% shares of MP in area and production respectively. Coriander yield is much more uniform as MP contributes 40% to area and 39% to production and RJ accounts for about 27%

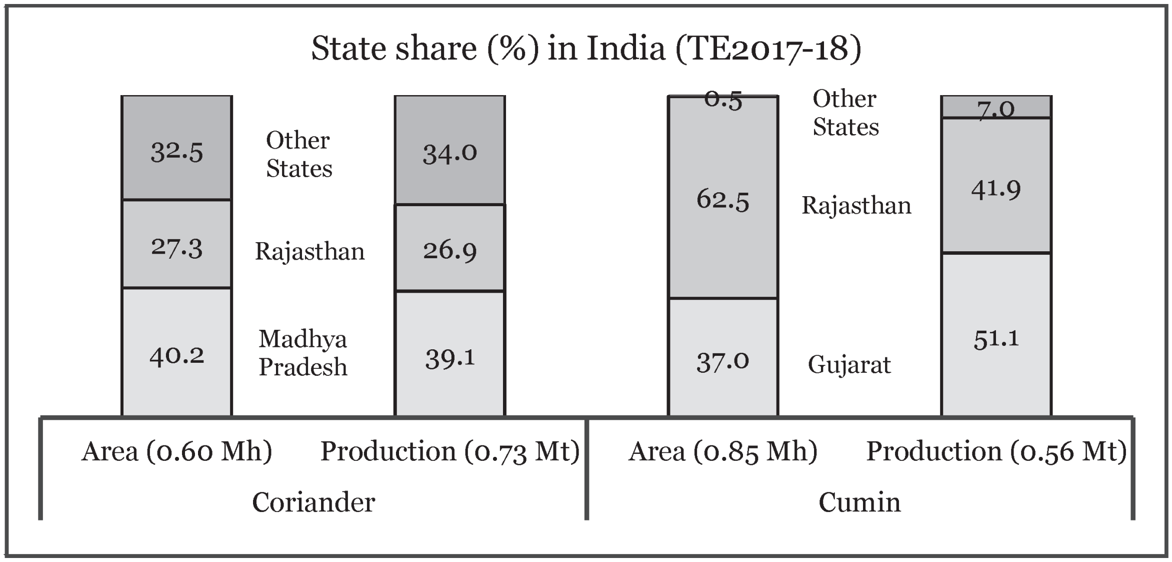


Figure 1: State share (%) of Coriander and Cumin in India

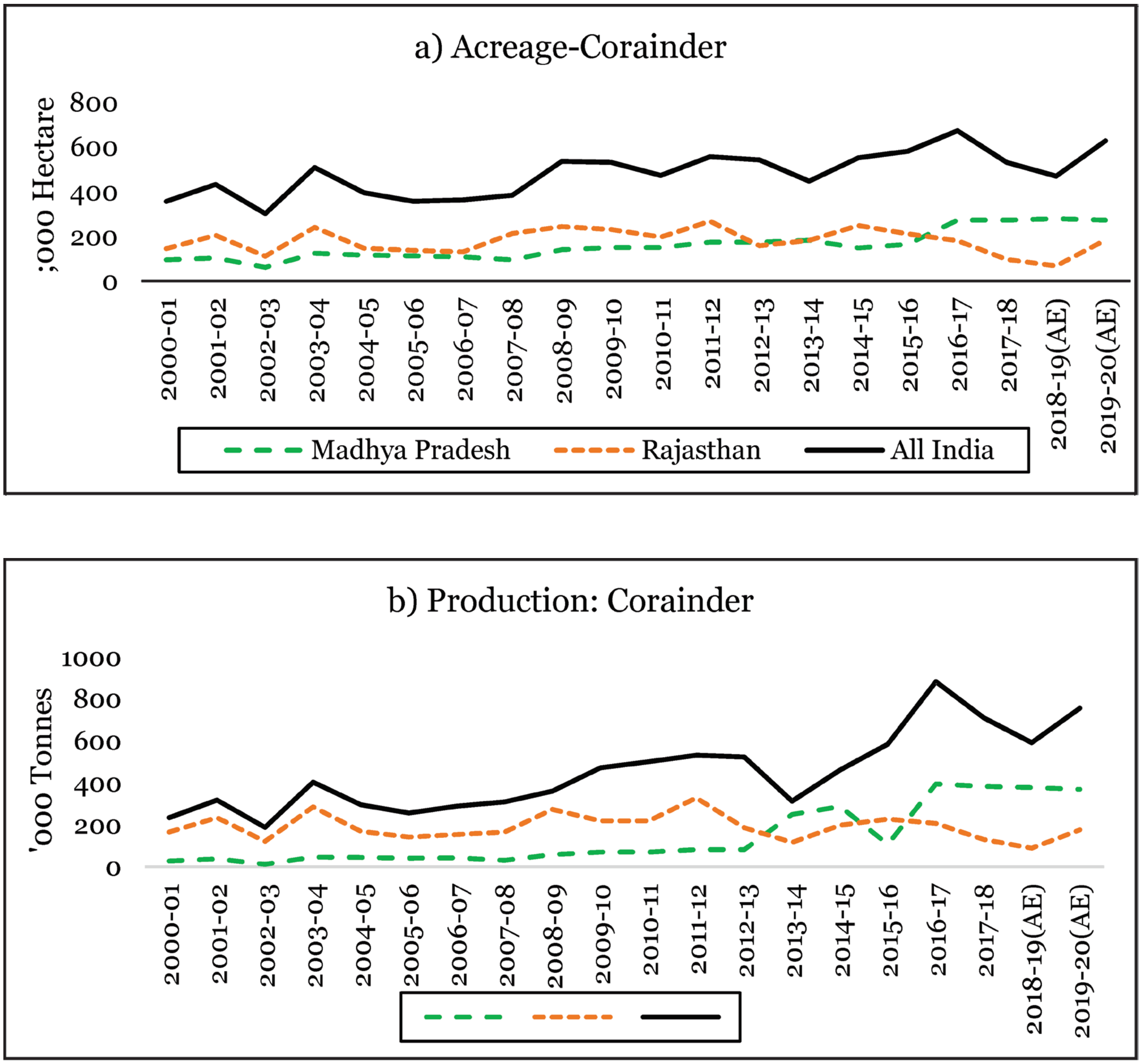


Figure 2: Area and Production of Coriander

of area and production. Rise of coriander in agriculture in terms of acreage and production occurred in a short timespan starting with 2013 (Figure 2) but continued more feebly in the years following 2016. By then RJ was moving away from coriander but cumin was gaining ground in that state (Figure 3).

Major coriander growing districts of RJ are in the south east proximal to the north-eastern districts of MP that followed in growing coriander, thus marking out a cross-state coriander growing region. Jhalawar, along with Baran and Kota districts, contributes more than 95% of the production of RJ. In MP, the major growing districts are Guna, Rajgarh, Mandsaur, Agar-Malwa (separated from Shajapur district) and Neemuch contributing 70% of its coriander production. All these coriander growing districts both RJ and MP are located in the Chambal river basin and served by Chambal River and its major dams and canals. Cumin is grown in soil with low moisture-retaining capacity in areas where weather remains dry and cold. In RJ, the major cumin growing districts are mostly located in the far west. Together, the districts Bermer, Jodhpur, Jalor and Nagaur contribute 85% of the state production, irrigated mostly by Indira Gandhi Canal and the Luni River. Within GJ state, the major growing districts, drained by Sabramati, Bhadar, Saraswati, Banas, Luni river, are Surendra Nagar, Banaskantha and Patan, Jamnagar, Rajkot and Porbander sprawled between northern to central part of the state and accounting for 70% of state production.

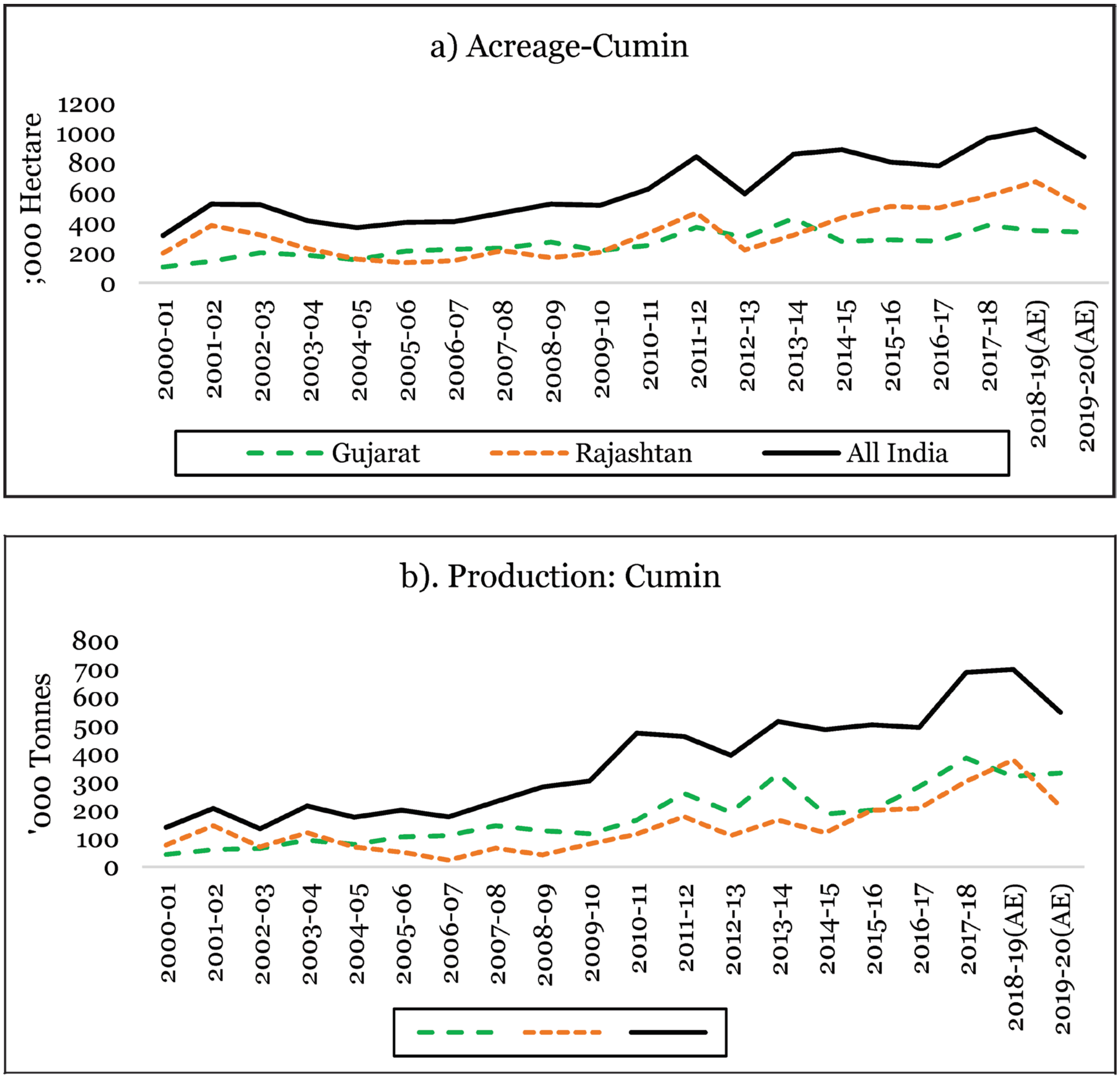


Figure 3: Area and Production of Cumin

In GJ where farmers, shifting from coriander, started experimenting with jeera for better returns of late, gram (chana) and mustard are grown traditionally. A good monsoon makes the situation favourable especially due to enough water in wells and dams stored from past rainfall for irrigation to grow the high risk crop but unseasonal rains in October or November raises the level of soil moisture in the growing district leading to fungal diseases. Map 1 shows the districts with concentration of the study crops.

On the basis of the numerous constraints, the soils of southeast Rajasthan were found most suitable for cultivation of coriander seeds (Sharma *et al*, 2014). However, as per MOA&FW official data (DES, Website), the state MP which was a minor producer of 0.17 million tonnes on 145 thousand hectares of land in 2000-01 was expanding acreage steadily while coriander acreage in RJ remained static in the ensuing decade and MP surpassed RJ in acreage and production in the year 2016-17 when acreage started even dipping in RJ. The figures 2 (a) and (b) suggest coriander production too followed the same pattern as acreage but the inter-state gulf is wider, which implicates a similar pattern of productivity movements in differentiating the states. In cumin seeds, the two western semi-arid states RJ and GJ were producers with similar performances to start with but over time RJ crossed GJ in acreage in 2014-15 but GJ remained ahead of RJ in cumin production. Thus, despite geographic advantages, the productivity performance over time of the leading state RJ is not vindicated for any of the two spices. Also, at the all India level, acreage and production of coriander followed RJ's patterns but the rise for coriander was comparative slower than cumin seed and production of both crops dipped in the last few sample years. The data for 2018-19 and 2019-20 are however official advance estimates pending finalization.

2.4. River Basins, Hydrology and the spatial nexus in context

While, the weather of the states or the specific districts that grow the crops is important for the planting and input decisions of farmers and the yield performance of the crops, the water nexus is much larger given that surface and ground water resources are dependent not just on the seasonal and local rainfall but also the water flows in rivers that get recharged by rainfall in the past and at upper reaches (Nepal *et al*, 2018, Ghosh *et al*, 2016) and also the man-made interventions so that catchment rainfall of recent times matter. The catchment in turn comprises of the rivers and their tributaries, sub-tributaries, canals and reservoirs and the extent of seepages into ground water all of which are enriched by rainfall in previous months or even years. This section gives a short description of the hydrology that can shape water availability of the growing states RJ, GJ and MP which lie in the Indo-Gangetic plains (IGP).

Yamuna and several other streams and rivers join river Ganga along the way as it flows in the south-east direction according to the slopes. Starting from a glacier in Uttarakhand (UT) as Bhagirathi, the Ganga drains Uttarakhand, Uttar Pradesh, Bihar, and finally West Bengal and Bangladesh. River Yamuna is a large tributary of Ganga that passes through Uttarakhand and Himachal Pradesh in the mountains and Haryana, Uttar Pradesh, Madhya Pradesh and Delhi in the plains to meet Ganga at Prayagraj, earlier Allahabad, in Uttar Pradesh. Fed by precipitation in the Himalayas, Karakorams and the Hindu-Kush mountains, river Indus enters India at Ladakh, which till recently was a part of the mountainous state J&K[1], and flows into Pakistan but five of its principal tributaries have longer courses in India before crossing into Pakistan out of which, Satluj, Beas and Ravi help in irrigating a number of Indian states. The Indus Water Treaty (IWT) signed by India and Pakistan in 1960, guides water sharing between the two countries. In the large Indian catchment, the riparian states of Indus include not only Punjab, Himachal Pradesh and J&K but also Rajasthan and Haryana. Linked to upstream Indus, many other rivers flow into Pakistan or Afghanistan after touching Ladakh.

Independent of the main rivers in the IGP are the seasonally inland rivers like Luni, Kantla, Ruparel and Ghaggar-Hakra of Rajasthan and Haryana. In GJ, Banas, Saraswati, Sabarmati, Mahi, Narmada, and Tapi River are independent major rivers. Banas in the north, originating in the Siranva hill in Sirohi in Rajasthan, flows by the foot hills of Abu and disappears in the desert. Saraswati takes its birth at Koteshvar near Ambaji, flows by Siddhpur and Patan and merges into the desert (WebIndia, Website). Sabarmati, one of the biggest rivers of north Gujarat, originates from the Dhebar Lake in Rajasthan and flows towards the Gulf of Cambay. Mahi is joined by the Bhadar, the Anas, the Panam and the Meshri. Tapi comes from the Satpura ranges near Betwa and enters Gujarat at Kakarapar. It flows around Surat and Rander and falls into the sea.

Historically, interventions on a river basin were meant primarily for flood control by holding, extracting and diverting natural rain water by gravity-flow but in the Indus basin, poor drainage, proliferation and deepening of wells and shifts in river courses are stronger challenges than floods. In the northwest, where the study regions lie, storing water from excess rainfall in a year for redistribution and use in the future if and where needed is the main form of intervention. The stored water in a reservoir, often equipped with a hydro-power plant installed, is also useful for generating electricity though dams have a limit to the holding capacity, beyond which excess watering becomes the problem.

Tehri Dam and Bhimgoda barrage are two dominant interventions to divert Ganga water upstream of Prayagraj, where Ganga is again recharged by Yamuna which has a number of tributaries like Tons, Chambal, Hindon, Betwa and Ken and barrages managed by multiple state governments. Further downstream, Ganga is enriched by more rivers and their sub-tributaries. After meeting Yamuna, Ganga is intervened by several multipurpose projects including the Ban-Sagar dam on Sone in Madhya Pradesh, Rihand valley project (RVP)[2] on a tributary of Sone, Matatila and Rajghat on Betwa river between Madhya Pradesh and Uttar Pradesh. The Chambal river project (CRP)[3] with dams Gandhi Sagar, Jawahar Sagar, Rana Pratap Sagar, and Kota Barrage between Rajasthan and Madhya Pradesh, is major step to control Ganga water distribution among eastern and western states including Madhya Pradesh and Chhattisgarh (earlier, part of MP) and Rajasthan. Associated with the Gobind Sagar reservoir and four spillway4 gates, Bhakra-Nangal (BN) multipurpose dams in Himachal Pradesh on the Sutluj River holds excess monsoon waters for regulated release irrigating Punjab, Haryana, and Rajasthan and generating power helping six partner states with ground water harvesting. Starting as Rajasthan feeder canal from the Harike Barrage, Indira Gandhi Canal (earlier Rajasthan Canal) flows through Punjab, Haryana and seven desert districts of Rajasthan, bringing Himalayan waters from Sutluj, Beas and Ravi for irrigation. Eastern Rajasthan is served by Jakham dam and Mahi Bajaj sagar and shares water and power from CRP with Madhya Pradesh. Numerous dams like Dharoi, Hathmati, Harnav, Guhai are associated with Sabarmati and proximate rivers of Gujarat and Rajasthan

Electrical, diesel or solar power is demanded by surface water, ground water, drip or lift irrigation. Presently surface irrigation system is widely followed in seed spices cultivation causing large water losses (Harisha *et al*, 2017). Micro-irrigation techniques backed by equipment and electricity is emerging as a method for delivering water precisely at the roots but is as yet rather costly. Water management is crucial for agriculture. Past rainfall not only accumulates water in reservoirs but also moistens the soil and recharges ground water. Ground and surface water reserves are not independent because wells draw from streams, canals and rivers laterally. The future of monsoon rainfall is extremely uncertain. Sensitive, conjunctive and adaptive water management has become essential in light of the threat (Dhawan, 1995, Shah, 2012). More details of river hydrology and interventions are provided in official documents and literature (Singh *et al*, 2020).

3. METHOD

The analysis uses an econometric model to estimate production of a crop.

$$Y = f(X_1, X_2, X_3, X_4, \dots \dots X_i) + e \qquad (1)$$

In which Y is the dependent variable indicative of production and X is a set of explanatory variable, considered relevant based on theory. The marginal effect (ME) of a change in any factor i is mathematically given by

$$dY/dX_i \tag{2}$$

Where

Now, $d(Y) = \Sigma\, ((dY/dX_i) * \Delta\, (X_i))$ (3)

Assuming e is small the sign of ME is used to assess the effect of a variable as favourable (positive) or adverse (negative)

3.1. Seasonality, Spatiality and rainfall shortage in recent times

The spatial unit of rainfall is the meteorological subdivision (MET) of which 17 are considered for the reason (see Table 1). They are primarily chosen for their rainfall effects on the study states based on both proximity and river linkages (see section 2.4) but the final specification is decided at model selection. Presuming borders of METS and political states do not coincide sharply an adjoining MET expectedly has commonality of climate with border districts. Specifications made of the growing season are not rigid neither constrained over time, covering 28 months (January of previous year to April of following year). Temperatures relate to the growing seasons and the METs within the study state only.

Pre-Season year (PS): Previous year June to December rainfall and January to April of Current year.

Monsoon season (MS): Rainfall in May to September, the monsoon months.

Post-Monsoon Late-season (**PM**): October to December, post-monsoon.

Growing season (GS) – January to February

Late-season or Harvest (HS) – March to April.

3.2. Model to explain crop Production

The model is specified in two stages. In the first stage area under a crop is estimated considering substitution possibilities among crops and with past acreage as the dynamic trend term (Nerlove, 1958). In the second stage its yield is estimated considering weather parameters, economic variable with input cost and substitution possibility and a time trend if demanded. Production is the product of area and yield.

Adaptive expectations (Nerlove, 1958) as well as rationality (Sheffrin, 1983) underlie subjective expectations formed about crop price (Rs. per Kg) or alternately returns or revenue from crop (Rs/hect) to be fetched only after harvest. Possible substitute crops are identified using pattern and calendar of cropping in the region and after each of them is considered individually, only those with statistically significant coefficients are retained as competing crops. The average of the identified competing crop prices or returns is used in the equation. The model incorporates water variables (W) shaped by rainfall by itself in various hydrologically linked regions but rainfall can be qualified by irrigation which aims to bring control over the water. Data on the method of irrigation, especially use of micro-irrigation technology is not available but the method, it is presumed based on literature (Suresh, 2020), will draw on the sources like natural rainfall or river, wells or canals from where water can be pumped. Irrigation (IRG) measured as land area under different sources, however, is basically infrastructure and has limited variation over time. In the case of the yield per hectare, the interacted water variable is standardized (deflated) by the crop area as estimated in the first stage. For simplicity and to allow variables to take zero values, the model is estimated in linear form, but allowing for quadratic and interaction terms. Intense use of maps of crop clusters (Map 1), river basins and METs are made when specifying the model.

For any crop

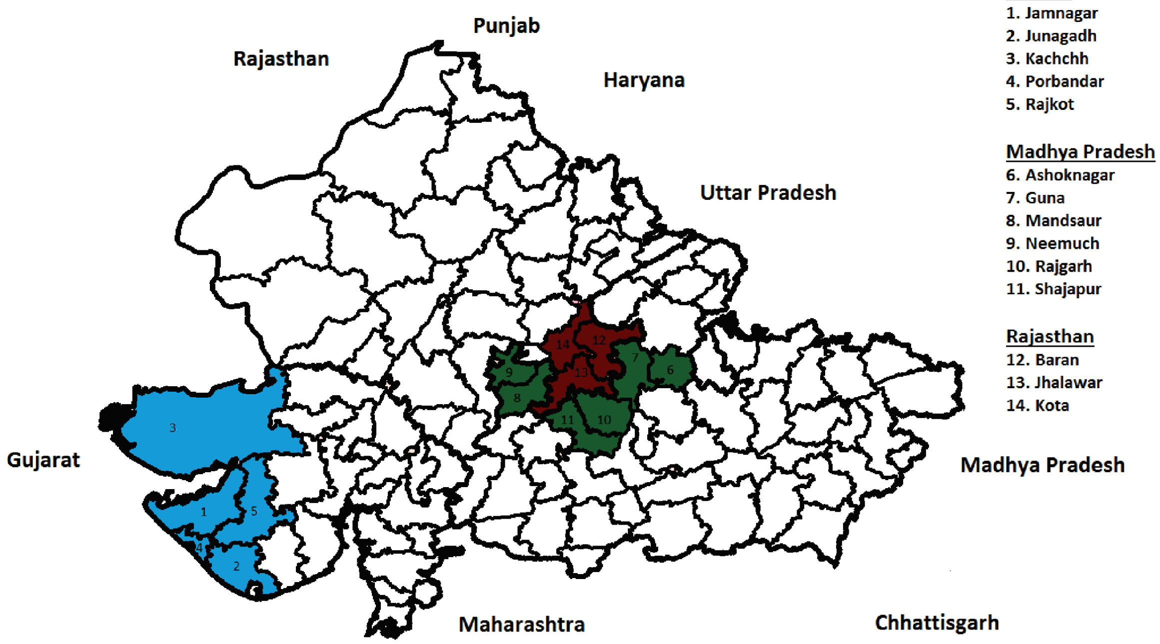
$$A_t = a_0 + a_1 A_{t-1} + a_2 P_t + (\Sigma a_{3j} * W_t^j) + \Sigma a_{4S} IRG_{ts} + \Sigma a_{5z} Z_{tz}, \tag{4}$$

$$\begin{aligned} Y_t &= b_0 + b_1 t + b_2 p_t^C + b_3 p_t^s + \Sigma b_{4j} * w_t^j + \Sigma b_{5s} I_{ts} \\ &+ \Sigma b_{6mMf} * TX_{tmMf} + \Sigma b_{7mMf} * TN_{tmMf} + b_{8k} D_{tk} + \\ &\Sigma b_{9mM} * R_{tmM}^2 + + \Sigma b_{10z} Z_{tz}, \end{aligned} \tag{5}$$

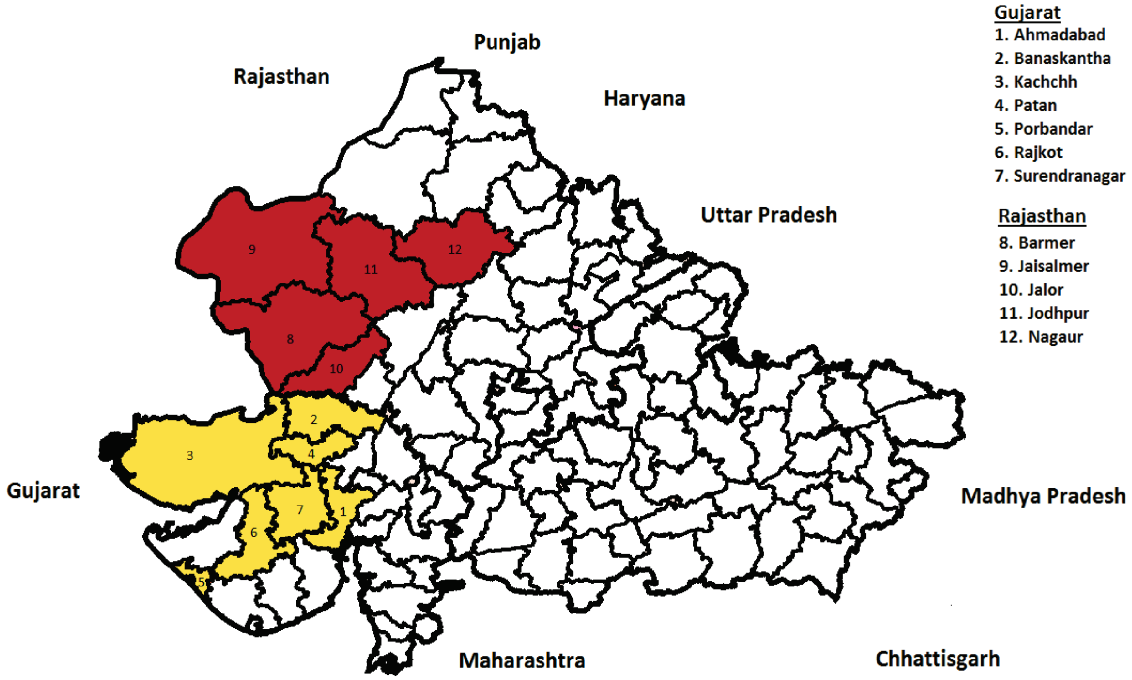
A_t = area in hectares under study crop, Y_t = yield (Kg) per hectare of study crop, $P_t = P_{t1}$ or P_{t2} (equation 4) and $p_t = p_{t1}$ or p_{t2} (Equation 5) in alternate specifications where $P_{t1} = (WP^C_{tm})/(WP^s_{tm})$, $P_{t2} = (WP^C_{tm} * Y^C_{t-1})/(WP^s_{tm} * Y^s_{t-1})$, $p^C_{t1} = (WP^C_{tm})/(WP^F_t)$, $p^C_{t2} = (WP^C_{tm} * Y^C_{t-1})/(WP^F_t)$, $p^s_{t1} = (WP^s_{tm})/(WP^F_t)$, $p^s_{t2} = (WP^s_{tm} * Y^s_{t-1})/(WP^F_t)$,

WP_t is the corresponding wholesale price (WSP) of crop in previous year, or latest MSP or

Coriander Rabi (Area): Gujarat, Madhya Pradesh and Rajasthan



Cumin Rabi (Area): Gujarat and Rajasthan



Map 1: Crop cluster Map of Coriander and Cumin

the average of both, $W^j_t = W^j_{t1}$ or W^j_{t2} and $w^j_t = w^j_{t1}$ or w^j_{t2} in alternate specifications where

$W^j_{t1} = R_{tMm}$, $W^j_{t2} = (R_{tMm})$ *IRG_{ts} (Equation 4) and $w^j_{t1} = R_{tMm}$, , $w^j_{t2} = (R_{tMm})$ *I_{ts}, $I_{ts} = IRG_{ts} / \mathrm{Exp}(A_t)$ (Equation 5).

Where R_{tMm}= rainfall averaged across different alternate sets of M and m

IRG_{ts} is command area under any irrigation sources

TX_{tmMf}= maximum of daily temperatures or their average across M, m and f of growing season

TN_{tmMf} = minimum of daily temperatures or their average across M, m and f of growing season

D_k = kth dummy variable for any known change in technology or policy,

$Z_{tz} =$ any other relevant z^{th} variable

Subscripts: t is year (2000-01 onwards), M=met region (1, 2…17), m= month (1…23), f= fortnight (1, 2) in any m^{th} growing month, s= source of irrigation (Canal=1, well and tank =2 and others = 3). Superscripts: C= Study crops, s= Substitute or competing crop (1, 2, . .n), F = inputs which are fertilizer nutrients Nitrogen (N), Phosphate (P) and Potash (K) together, chemical fertilizer containing only N and P (DAP), chemical fertilizer containing Ammonium Sulphate (NS), Pesticides (pcd), Insecticides (icd), j= jth water variable identified by season and region of rainfall, exp = expected value of crop area = area estimated in equation (4). Error (E) is the difference (%) of estimate over observed officially recorded value from data.

In vast hydrologically linked spatial expanses with temporal storage possible, the large number of rainfall variables reduces degrees of freedom and enhances the possibility of multicollinearity caused by spatial interdependence of weather. Data reduction is accomplished by checking the statistical effect of each rainfall variable at a time and averaging the causative variables categorized by the four seasons to make up a set of rainfall values in a water variable with a cumulative effect in any specific direction. Autocorrelation is corrected where indicated by DW statistic, stability of the equation is tested by comparing the coefficients model estimated after dropping the last sample year the errors are examined for stationarity by Dickey-Fuller (DF) test statistics. Selection of the equation for further analysis is made keeping the following mathematical and economic conditions on diagnostics:

$$\text{Abs } [a_1] < 1,\ a_2 > 0,\ b2 > 0,\ b_3 < 0,\ b_9 < 0,$$

All t-statistics (except a_1) of coefficients >1.96 (level of significant at 5%). $R_{bar}^2 > 0.90$, DW near 2 and E is between +5% and -5% in the sample period with the direction of estimate matching by and large with data. The predictive power of the model is also assessed by matching a one-step forward forecast for 2018-19 with the actual data available. While a number of explanatory variables are tried for, to avoid over-fitting two terminal sample observations are dropped to re-estimate the model, checking the robustness of the coefficients and matching the post-sample forecast with actual values reported.

A negative effect of a water variable can indicate either damage to planting or an incentive to allocate acreage towards alternative water demanding crops. For crop yield, a positive effect is the ideal while a negative coefficient is a sign of shortfalls in water management, especially poor drainage or flooding. An adverse effect of rainfall in periods preceding sowing (PS, ES, MS) is a sign of excess soil water which is harmful for both crops and may implicitly also signify inadequate water management of river basins or poor drainage from land of past rainfall or past irrigation in a previous crop or simply in-optimal choice of crops. An interaction between PSR and canal, ideally positive, is expected though river water flow under gravity or the sale of hydro-power by grid (Figure 2) for ground water irrigation in the study state can act as other conduits directly or via micro-irrigation implements. Temperature effect reflects agronomic necessities for fruition at different growth phases. Time trend will be positive for yield in the presence of technical progress not captured by the other variables in the model while the dynamic lagged acreage variable in the area equation reflects the effort to catch up and adjust to desired acreage by farmers. The results based on estimated equations are summarized in Table 3 (A) and (B).

4. FINDINGS

Economics has a significant role in driving production. In the case of acreage, the wholesale price (WSP) of the crop as well as of some probable substitute crops have been important. Relative returns appearing in two of the equations as statistically significant make the crop yield dynamics important for cumin planting but in other cases of yield and all cases of acreage, relative price alone mattered. Gram (gm) was a competing crop for coriander and cumin in RJ. Rapeseed-mustard (rm) competed for land with cumin in both RJ and GJ just as Onion (on) did with coriander in RJ and MP. Onion competed with cumin too in GJ. Potato (pt) was a substitute for coriander in MP and for cumin in GJ. Although the substitutes fall under the group's pulses, oilseeds and vegetable in nearly all cases, cereal rabi rice also appears statistically significant as a substitute of coriander in MP but rabi rice like potato is a minor product in the state. For yield, WSP mattered in relation to input prices that figure in the cost of cultivation. Price of fertilizer as an input appeared in all cases but nutrients N, P and K were included only for coriander in MP and cumin in RJ. In the other two cases, i.e., coriander in RJ and cumin in GJ, potassium (K) price did not matter. Ammonium Sulphate (NS) price emerged as a determinant in all cases for the seed spices. Except MP, pesticide (pcd) price appeared as a cost in all cases and insecticide (icd) price also mattered for coriander in RJ and cumin in GJ.

Past rainfall (PS) in Madhya Pradesh (EM, WM) and Chhattisgarh (CH, earlier part of Madhya Pradesh) and in neighbouring

Table 1: Abbreviations (Abb) of meteorological regions and average rainfall of sample

Abb	*Meteorological regions*	*Monsoon Rainfall (mm) (1985-2019)*	*Annual Rainfall (mm) (1985-2019)*
WU	West Uttar Pradesh	683	783
UT	Uttarakhand	1280	1628
HD	Haryana Chandigarh And Delhi	505	622
PJ	Punjab	528	668
HP	Himachal Pradesh	826	1293
JK	Jammu & Kashmir	515	1172
WR	West Rajasthan	282	322
ER	East Rajasthan	602	652
WM	West Madhya Pradesh	856	929
EM	East Madhya Pradesh	1015	1125
GR	Gujarat Region, D & N Haveli	828	865
SK	Saurashtra And Kutch	522	551
KG	Konkan & Goa	2756	2938
MM	Madhya Maharashtra	662	814
MT	Marathwada	677	817
VD	Vidarbha	919	1059
CH	Chhattisgarh	1109	1261

Table 2: Compound Annual Growth Rate (%)

	Area	*Yield*	*Prod*	*Area*	*Yield*	*Prod*	*Area*	*Yield*	*Prod*
Coriander									
	Madhya Pradesh			Rajasthan			All India		
TE2002-03 - TE2007-08	3.9	4.1	8.1	0.8	-3.2	-2.4	0.2	2.7	2.9
TE2008-09 - TE2013-14	9.2	15.1	25.6	0.7	0.6	1.3	3.8	3.4	7.3
TE2014-15 - TE2019-20	10.3	2.3	12.8	-9.9	5.8	-4.7	1.1	8.4	9.6
TE2002-03 - TE2019-20	7.0	9.3	17.0	-1. 6	0.0	-1.6	2.4	3.7	6.2
Cumin									
	Gujarat			Rajasthan			All India		
TE2002-03 - TE2007-08	8.2	7.6	16.4	-11.2	-2.6	-13.4	-1.3	6.1	4.8
TE2008-09 - TE2013-14	8.7	6.1	15.3	13.5	12.6	27.9	10.3	4.0	14.7
TE2014-15 - TE2019-20	1.1	6.7	7.9	12.5	4.5	17.6	3.9	2.8	6.8
TE2002-03 - TE2019-20	5.2	5.8	11.3	4.0	2.7	6.8	4.4	4.0	8.5

east-Rajasthan (ER) hurt coriander acreage in MP possibly, leaving land wet from the previous kharif cultivation while no such adverse reaction to past rainfall is observed for coriander acreage in RJ. On the other hand, past rainfall in neighbouring GJ (GR) supports the canals to promote coriander planting in MP but past rainfall in growing regions of RJ (ER) independently supports coriander planting in RJ showing the positive effects of past rainfall. Unlike for coriander, acreage under cumin in RJ is hurt by past rainfall in various regions as in the mountains (JK), neighbouring MP (WMP), Gujarat (GR) and Maharashtra (KG) and in a part of the state itself (WR). Canal irrigation has a serious role in the adverse effects. In Gujarat cumin acreage show no adverse reaction to past rainfall and is helped by PS rainfall in the mountains (HP) and in neighbouring Maharashtra (KG, MM) and a part of MP (WM) by irrigation or river flows.

Although, the crops are not demanding in water, a good monsoon reflected by rainfall in a wide expanse of areas, in mountains like UT, HP and JK and in parts of plain states Uttar Pradesh, Gujarat, Rajasthan, Madhya Pradesh and Punjab with support from irrigation helped acreage expansion of both the crops. Only cumin acreage showed adverse reactions, to monsoon rainfall in JK and WM and to rainfall in HC respectively in RJ and GJ. The effect of monsoon rainfall in JK is contrary for cumin area between GJ and RJ reflecting differential water management. Coriander acreage showed no negative reaction to monsoon rainfall anywhere.

Post-monsoon (PM) rainfall is expected to hurt acreage rather than help, but coriander did benefit from this rainfall in certain regions but discouragement to sowing came from the growing region rainfall. Rainfall in both WM and EM hurt coriander acreage in MP, and that in WR hurt its area in RJ while cumin area in GJ had a negative reaction to rainfall in SK. Soil moisture seems to be sufficient from a good monsoon but post monsoon rain creates excess moisture for the sensitive crops. In MP and RJ coriander follows irrigated rice or soybean while cumin in GJ follows less water demanding bajra, jowar, cotton, and castor.

Previous rainfall has meagre implications for yield, with PS rainfall in WR, WM, WU helping cumin and that in PJ and HC helping coriander yield in RJ with irrigation. Mountain rainfall was mostly damaging. Unlike for acreage, monsoon rainfall effect is weaker on yield, with coriander being affected favourably by rainfall in interior Maharashtra (VD, MT) in MP and rainfall in the mountains in RJ. Evidence of negative effect of monsoon rainfall is only for coriander yield in MP getting hurt by rain in GR. For cumin yield, beneficial effects of monsoon rain in Maharashtra (MM) and Rajasthan (ER) were found only in GJ whereas rainfall in various regions (WU, GR, ER and HP) hurt the yield in both states.

Growing season post-monsoon rainfall was of little effect also. Cumin yield was helped by this GS rainfall in GJ (GR, SK) and rainfall in Rajasthan (ER). Negative impact of regional growing regions was observed for cumin and for Madhya Pradesh for coriander while mountain rainfall (HP, UT) was unfavoruable for coriander yield in Rajasthan. Winter season (WS) rain in parts of Gujarat (SK) helps cumin yield in both states, rain in Rajasthan (ER) and the other part of Gujarat (GR) hurts both crops in Rajasthan and the two parts of Madhya Pradesh have contrary effects on coriander yield in Madhya Pradesh. Curiously, harvest season (HS) rainfall as defined, has some positive effect on coriander in MP suggesting the presence of late sown crop.

Irrigation effect, independent of rainfall, was observed only for coriander area, with a negative effect of well irrigated area in MP and positive effect of canal irrigated area on RJ but the extent of irrigation does interact with rainfall in and out of the study states with varied effects. Interaction effect with canal irrigation is more visible with PS rainfall and limited or absent with other seasons reflecting water flows in rivers and remnant water in the soil. Negative interactions with PS rainfall in Rajasthan, Madhya Pradesh, Maharashtra and JK suggest diversion of acreage to water seeking crops but interaction between irrigation and rainfall showed little effect on crop yields Temperature effect is generally positive with favourable effect of a rise in minimum temperature in the growing season (GS) on yield

Table 3 (A): Direction of impact of Economic, Spatial Rainfall and Irrigation factors to Acreage: Estimation from Econometric Equation

			Rainfall						*Irrigation*
		Price	*Pres Season (PS) (Jun* -April)*		*Monsoon Season (MS) (May - Sept)*		*Post-Monsoon (PM) (Oct -Dec)*		
Crop	*State*	*Substitutes*	*+ve*	*-ve*	*+ve*	*-ve*	*+ve*	*-ve*	
Coriander	Madhya Pradesh	WSP rc, pt, on	GR^1	(ER, WM, EM)^1, CH	EM, UT, GR^1		ER, GR	WM, EM	-
	Rajasthan	WSP on, gr	ER		UT1, GR, HP^1		ER, HP	WR	-
Cumin	Rajasthan	WSP rm, gr	WU	JK1, WM, GR, (WR, KG)^1	HP, ER, WR, GR, PJ	JK, WM			-
	Gujarat	WSP rm, pt, on	HP, MM^1, (KG, WM)1		EM^1, JK, WU, UT	HC		SK	-

Notes: *Crop prices mention the identified competing crops. WSP=wholesale price of crop, MSP=minimum support price of crop, Substitute crops: rc=rice, gr=gram, rm= rapeseed mustard, pt=potato, on=Onion. Irrigation 1: Canal. Sample: 2000-01 to 2017-18. * Previous Year

Table 3(B): Direction of impact of Economic, Spatial Rainfall and Irrigation factors to Yield: Estimation from Econometric Equation

			Rainfall											
		Price	*Pres Season (PS) (Jun* -April)*		*Monsoon Season (MS) (May - Sept)*		*Post-Monsoon (PM) (Oct -Dec)*		*Winter Season (WS) (Jan-Feb)*		*Harvest Season (HS) (Mar-Apr)*			
Crop	*State*	*Input Price*	*+ve*	*-ve*	*+ve*	*-ve*	*+ve*	*-ve*	*+ve*	*-ve*	*+ve*	*-ve*	*Temperature*	*Irrigation*
Corian-der	Madhya Pradesh	WSP N,P,K, S		WM	MT, VD	GR		WM	EM,	WM	MM, WU		+ : WS-WM, WS-EM -:	3-
	Rajasthan	WSP DAP, pcd, icd, S	(HC, PJ)^1	UT, WR, ER, WU	JK, UT			UT,HP	PJ	ER, GR			+ : PM-WR, - :	1+
Cumin	Rajasthan	WSP N,P,K, pcd, S	WU, WM, UT, HC	HP		WUP, HP	GR, ER, SK	WR	SK	GR, ER, UT			+ : WS-ER - : WS-WR	-
	Gujarat	WSP DAP, pcd icd, S	(WR, WM)^1		MM, WR	GR, ER	SK, WR	ER, MM, GR	SK				+ : - :	-

Notes: Irrigation 1: Canal, 3: Oth. * Crop prices deflated by NPK, DAP-Diammonium phosphate, S-Ammonium Sulphate, pcd- pesticides, icd- insecticides. Temperature – gives sign (direction of effect), season and MET e.g., +: WS-WM: positive effect of West Madhya Pradesh in Winter Season. * Previous Year.

of the crops, an only exception of negative effect being the case of cumin yield in Rajasthan.

5. CONCLUDING REMARKS

Diversification of agriculture to horticultural, commercial and less water demanding crops can help in making sustainable use of land in resource-scarce regions and in enhancing farm income and food processing. Exercises with data on three western states for two seed spices suggest significant effects of both economic and weather parameters on production but water variable as captured by rainfall has a wide spatio-temporal dimension depending on interventions, hydrology and water management.

Notes

1. Ladakh is now an Union Territory separate from J&K (Jammu& Kashmir) since 31st October, 2019
2. Govind Ballabh Pant Sagar, Rihand dam
3. Rana Pratap Sagar, Gandhi Sagar and Jawahar Sahar (Kota), Kota barrage
4. Spillway is a passage for surplus water over or around a dam when the reservoir itself is full. They are safety features for the dam.

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