# AN EMPIRICAL ANALYSIS OF DETERMINANTS OF CROP DIVERSIFICATION IN PUNJAB

*A Thesis Submitted to the Central University of Haryana*
*for the Award of the Degree of*

**DOCTOR OF PHILOSOPHY**

**IN**

**ECONOMICS**

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# DECLARATION

I, hereby, declare that the thesis entitled **'An Empirical Analysis of Determinants of Crop Diversification in Punjab'** submitted to Department Economics, Central University of Haryana for the award of the degree of Doctor of Philosophy, is a record of original research work done by me under the supervision and guidance of Dr. Ajeet Kumar Sahoo, Assistant Professor, Department of Economics, Central University of Haryana. The content of this research work has not been submitted in part or in full for any degree or diploma in any other university/institution.

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# CERTIFICATE

This is to certify that the thesis entitled '**An Empirical Analysis of Determinants of Crop Diversification in Punjab'** being submitted to the Department of Economics, Central University of Haryana for the award of the degree of Doctor of Philosophy in Economics, appears as the record of original work done by Ms. Poonam Rani (Registration No. CUH1700310053) under my supervision and guidance. The matter presented in this thesis has not been submitted in part or full, for any other degree/diploma of this university or any other university/institution.

I consider the present work is fit for being evaluation.

| **Forwarded by** | **Research Supervisor** |
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**Poonam Rani**

# CONTENTS

| *Particulars* | *Page No.* |
|---|---|

# LIST OF TABLES

# LIST OF MAP AND FIGURES

# LIST OF APPENDICES

# *Chapter-1*

## *An Introductory Analysis*

# CHAPTER-1

***An Introductory Analysis***

1.1 Introduction

1.2 Concept of Crop Diversification

1.3 Crop Diversification at India Level

1.4 Crop Diversification in Case of Punjab

1.5 Rationale and Objectives of the Study

1.6 Structure of the Thesis

# Chapter 1

# An Introductory Analysis

*"Crop diversification has emerged an important alternative to attain the objectives of output growth, employment generation and natural resources sustainability in the developing countries".*

*Petit and Barghouti (1992)*

## 1.1 Introduction

The agriculture sector is a primary and oldest source of income and employment in emerging economies (Mohammad, 1981). Therefore, sustained growth in the sector is a prerequisite for the development of these economies. Such growth is even more eminent in those countries, where more than half of the country's population is dependent on the agriculture sector and related activities for their livelihoods. Since the beginning of reforms in the1960s, a dominant agricultural system has followed in developing economies. Such economies have constantly put efforts on improved production of cereals particularly rice, wheat, and maize (Hutagaol, 2006).

India is not an exception. High population growth in economy and opening of the agriculture sector for export are placing immense pressure on farmers to produce more. However, the growth in farm production is constraint by accessibility of resources. Therefore, to increase agricultural production, application of high-yielding varieties (HYVs) was introduced as a part of the Green Revolution. HYVs gave higher return than earlier cultivators, as result agricultural production of food crops has increased dramatically. It observed that the area under crops cultivation has increased by 8 percent between 1960 and 1987, productivity increased by 51 percent and production nearly doubled by 81 percent in the country (Vaidyanathan, 1994).

Undoubtedly, initially green revolution brought the economic prosperity in Indian farming. However, many studies claim that this revolution had shown adverse impact on production by the mid-1990s. Although, the food grains production elevated at 3.5 percent per annum during 1980s, but it had decelerated to 1.5 percent from 1990-96. Thereafter, country has shown witnessed drastic change in the sector. A highly commercialized agriculture system has replaced the traditional diversified cropping system with the mono-cropping system (Hutagaol, 2006). Adaptation of new technology, higher application of fertilizer and pesticide practises on fixed land, and lack of crop rotation gave birth to various problematic phases such as degradation of natural resources, reduced soil quality, depletion of groundwater, and various socio-economic aspects of the land cultivators (Sajjad & Prasad, 2014). For India, (Sehgal & Abrol, 1994) estimated that 64 percent of the land area is degraded due to adverse impacts of this revolution. In particular, an intensive crop production has threatened the long-term sustainability of agriculture (Eicher, 2003). Under such a scenario, these fundamental questions arise (i) what are the most significant factors striving for agricultural production in such economies where agriculture resources are scarce and opportunities to enhance productivity are dwindling? (ii) what is the possible way to achieved stainable production in such a scenario? (iii) whether farmers are producing the optimal output from the existing pattern of crops and inputs used or not? (iv) what is the possible risk-coping appliance to enhance the agricultural productivity against the weather shocks?

The various policy makers have suggested for crop diversification choice, to combat with such challenges and acceleration in growth. Crop diversification considered as an instrument to achieve development goals by anticipating a shift in production activities, adjusting in the economic environment, and deals with the challenges of natural resources degradation. Ray et al. (2005) and Acharya et al. (2011) recommended that crop diversification can minimize the adverse effect of the monoculture system. By changing to the cropping patterns, it is possible to minimise the area under high input requiring crops; and maximise the area under crops that needs a smaller amount of input and enrich soil health. In the context of Sudan, it was found that diversity in crops reduces income variability (Guvele, 2001) but in the case of China it was found that the crop diversification improves their farmers' income (Van den Berg et al., 2007). Further, Kar et al. (2004) estimation shows that crop diversification helps to mitigate drought effects and increased water use efficiency in upland areas. Therefore, crop diversification has been pursued as a way to improve the long-term variability of agriculture sector by increasing the profitability and overall stability of the sector.

### 1.2 Concept of Crop Diversification

Crop diversification refers with the structural change in crop-mix in any geographical economy. A change in inter-crop and intra-crop over time within the crop growing sector is directly related to the progressive of agricultural economy. The progress in technology has changed the cropping pattern, and it shifted the traditional varieties of crops by new high yielding varieties crops. In India, "within the cropping sector mainly the crop diversification has been taking place in terms of a shift in area from food crops to non-food crops" (Pandey & Sharma, 1996).

There is two type of diversification in agriculture: - (i) crop diversification and (ii) enterprise diversification. This study mainly focuses on crop diversification which includes (a) shifting of one crop to other crops and (b) adding more crops to the existing cropping system.

## 1.3 Crop Diversification at India Level

Indian agriculture has been diversifying from traditionally grown less remunerative crops to more remunerative crops. This structure has rapidly changed after the green revolution. The area under commercial crops (non-food crops) has doubled since the 1960s and now equals half of the area under food crops (Vyas, 1996). Within food crops, area under superior cereals (i.e. rice and wheat) is increasing while that area under inferior cereals (like jowar, bajra, pearl millet, etc.) is declining. Studies that have particularly examined the change in cropping pattern in Indian context revealed that the highest area covered under food grain is in north-east region, north-west region, east region, and central region, while the southern region is the leader in production of non-food grain crops. The northern dry zone is more diversified than the northern transitional zone (Kumar & Gupta, 2015).

## 1.4 Crop Diversification in Case of Punjab

Punjab is an agriculturally rich state and holds a special status in Indian agriculture due to their most considerable involvement to the national pool of food grains such as around 70 percent of wheat and 50 percent in case of rice. The agrarian economy of Punjab has achieved a significant growth due to the advent of green revolution. The state has recorded largest increase in the index of production of cereals around eleven-fold during 1960-61 to 1994-95 (Lindsay et al., 1995) as a result the state attained self-sufficiency in food production and move from past food crisis. As results the state has observed a paradigm shift in its cropping pattern, from a diversified practice it has shifted to a specialized one, and relatively more remunerative crops (Sood et al., 2000). Primarily, the substantial area under input-intensive crops (mainly wheat and rice) have taken place at the cost of traditional low input crops, and become the most predominant crops in the state. They covered 44.07 and 36.03 percent of the cropped area in 2018-19 against 29.59 and 4.8 percent in 1960-61, respectively. The area under maize, millets, and groundnut has shifted with rice, while the area under gram, rapeseed/mustard, and barley has shifted with wheat (Sood et al., 2000). In the state, the largest portion of the food grain production around 95 percent of the entire comes from rice and wheat (Aulakh, 2002). It was the evolution of high-yielding varieties and better response of input resources in terms of fertiliser, pesticide, and water accessibility (Grewal & Sidhu, 1990).

Recently, the most progressive state has been under a deep economic crisis. The farmer's decision to produce a single-cropping pattern on fixed land has become a major challenging issue in the farming sector. The adverse effects of excessive use of synthetic inputs in post green revolution era are become a result of declining ground-water table, waterlogging, salinity, etc. Further, stagnant growth in agriculture productivity and wide variation in terms of income generation has been seen within state (Singh & Grover, 1991). Thus, by decelerating agriculture growth, the state has lost its pre-eminent position of being the state with the highest per capita income in the country. However, in 2014-15, Punjab stood at the seventh position in per capita income amongst 21 major states of the country. So that if current growth scenarios continue, it might be possible a surprise that the state slips further down in this hierarchy of large Indian states in terms of its per capita income. It is considering the negative agro-ecological impacts of recent adopting cropping system of Punjab. Therefore, suitable strategies for cropping system are needed in the state essential for sustainable agricultural development.

### 1.5 Rationale and Objectives of the Study

The importance of the agriculture sector of Punjab has been well recognised. Although, share of the sector has declined to the state domestic product (SDP), but it still has a significant role for the rural population, because it provides various ingredients of life to the people. The introduction of modern technology in mid 1960s' has brought a revolutionary change in the sector. The applications of advanced inputs and changing institutional factors have added a new dimension to agriculture. The emphasis was only given to produce rice and wheat to accomplish growing demand in the competitive market for food grain. Farmers are resorting to addition of more and more fertilizers to obtain higher yields or similar levels to previous years. As result, the sector has facing various environmental challenges such as an increase in soil salinity, increased pests and diseases infestation, depletion of water, and reduced bio-diversity. The monoculture system reduces non-food grain crops' production, leading to a nutritional imbalance in the area. The health of land soils has been impaired due to the emergence of multi-nutrient deficiencies and falling of organic carbon levels. The soils are presently operating on a negative nutrient balance. Thus, to sustain future agricultural development, it must be followed environment friendly cropping pattern.

In Punjab, crop diversification is a major component to drive a positive change in the state. Here, crop diversification is seen to address the problem of price fluctuation, environmental degradation due to excess use of pesticides, chemical fertilizers, water exploitation etc. (Johl, 1986). Beside this, crop diversification is also plays an important role in fulfilling basic needs and rising farmer income.

Thus it becomes inevitable in the presents scenario of Punjab, to verify the extent of crop diversification and its determinants. It has also been expected from crop diversification to be instrumental in mitigating the negatives effects of weather shocks. It is, therefore necessary to examine crop diversification on this standard. Similarly, crop diversification is also linked positively with productivity, and thus, enhances the economic efficiency of the farms. This is an interesting dimension of crop diversification. So estimating the economic efficiency of the farms; and determining the contribution of crop diversification on the economic efficiency of farms are also the key concerns of agriculture in Punjab.

Therefore, the presents study entitled *'An Empirical Analysis of Determinants of Crop Diversification in Punjab.'* aims at following six specific objectives:-

(i) To explore the trend and pattern of crop diversification in Punjab.

(ii) To identify the factors those determine crop diversification.

(iii) To assess the impact of weather shocks on crop productivity.

(iv) To examine the adaptation benefits of crop diversification against weather shocks.

(v) To estimate the economic efficiency of crop production in Punjab.

(vi) To determine the effect of crop diversification on economic efficiency.

### 1.6 Structure of the Thesis

The thesis is structured in six chapters. **Chapter 1: An Introductory Analysis** represents a brief summary that discusses conceptual framework of the study. In this chapter, rationale and objectives of the study is presented. **Chapter 2: Review of Literature** presents scientific reviews of literature on crop diversification and its various perspectives. **Chapter 3: A Temporal Analysis of Crop Diversification in Punjab's Agriculture** presents the performance and changing pattern of crops, and also identifies the factors those are responsible for this change. In this chapter, data has used from Directorate of Economics and Statistics (DES) of India and Economic and Political Weekly Research Foundation (EPWRF) for estimations. The composite entropy index (CEI) has been used for measure the degree of crop diversification. Further, rank concordance analysis has been used for the inter-temporal movement. **Chapter 4: Weather Shocks, Crop Productivity, and Crop Diversification: Adaptation Practices in Punjab** represents the relationship between weather shocks and crop productivity, along with the analysis of effectiveness of crop diversification to cope with such weather shocks. For this analysis two dataset has been used such as International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Indian Metrological Department (IMD). Additionally, fixed effect regression approach has been applied for panel dataset. The economic efficiency of farms in producing the optimal output from the given resources has been estimated in **Chapter 5: Economic Efficiency of Agriculture in Punjab.** The dataset has been used from a survey of "Comprehensive Scheme for Cost of Cultivation (CCS) of Principal Crops" administered by "Directorate of Economics and Statistics, Ministry of Agriculture". The two most popular DEA (Data Envelopment Analysis) techniques namely CCR and BCC models for crop production efficiency have been applied. Further, the super-efficiency slacks based measurements (SBM) model has been used to estimates most efficient tehsil among the fully efficient tehsils. Lastly, **Chapter 6: Major Findings and Policy Implications** draws significant policies implications based on findings of the study and conclude the thesis.

# Chapter-2

# Review of Literature

# CHAPTER-2

***Review of Literature***

2.1 Introduction

2.1.1 Literature Review on: Nature, Trends, and Patterns of Crop Diversification

*2.1.1.1 Global context*

*2.1.1.2 Indian context*

*2.1.1.3 Punjab specific*

2.1.2 Literature Review on: Determinants of Crop Diversification

*2.1.2.1 Global context*

*2.1.2.2 Indian context*

*2.1.2.3 Punjab specific*

2.1.3 Literature Review on: Crop Diversification and Economic Efficiency

*2.1.3.1 Global context*

*2.1.3.2 Indian context*

*2.1.3.3 Punjab specific*

2.1.4 Issues and Research Gap

# Chapter 2

# Review of Literature

## 2.1 Introduction

Review of existing literature is most important to any research attempt. It provides idea similar studies conducted elsewhere; to get an insight in to theoretical framework; method and approach; and the finding attained therein. Therefore, a comprehensive review literature is a subsequent part of any investigation. Besides obtained an idea about the past studies, the main purpose of review of literature is to identify the research gaps in the particular theme or issues. It also helps to a great extent to identify problem, formulate objectives, decide upon methodology, and exemplify the impact of the study. In view of above fact, in this chapter a review of previous research works has been complied to enable better understanding of the research in various dimensions. Thus, this chapter provides description of research works carried out by different researchers in the areas that is correlated to the objectives of this particular study. In this chapter: - the review of relevant literature has categorized into three sections. First section presents the reviews related to nature, magnitude, trends, and patterns of crop diversification. The second section presents the reviews associated with determinants of crop diversification, and particular impact of climate change. In the third section present the literature related to crop diversification and economic efficiency.

### 2.1.1 Literature Review on: Nature, Trends, and Patterns of Crop Diversification

#### *2.1.1.1 Global context*

Sichoongwe et al. (2014) explored the factors and intensity of crop diversity among small land holding size in the southern province of Zambia. Tobit model has been used to test the drivers of diversification. For this analysis they used data from secondary. The results found crop diversification has been affected positively and significantly by the factors such as landholding size, quantity of fertilizer used, plough tillage and market distance.

Rehima et al. (2013) initiated a primary study on 393 farmers to catch up the diversification status in Ethopia. The scenario of diversification has been seen by Margalef index of richness and Heckman two stage model. Probit and OLS has been worked out for estimating the factors affecting crop diversification in Ethopia. The variable gender has positive impact on diversification implying the probability of diversification is higher in female headed households. Further education, size of landholdings, number of plots and distance from market positively affects the diversification. The drivers such as knowledge about trade, association with social organization and fertility of plots have significant negative impact on crop diversification.

Joshi et al. (2004) identified determinants of agriculture diversification in South Asia. From the estimation, it was found that the agricultural diversification moved towards high-value commodities. It is because of the changing factors of development such as an increase in per capita income, changing food consumption patterns, increasing urbanization and infrastructure development. These drivers are encouraging for future growth and agricultural diversification. However, the degree of diversification has been seen less in most of the South Asian economies. It is because food security issues and the government policies are obsessed with self-sufficiency in cereals.

Benin et al. (2003) found the factors of crop diversification of inter-and infra-specific diversity in Ethiopian Highlands. Physical and household characteristics of the farms such as livestock assets and the proportion of adults are showing statistically significant impact on diversity among and within cereal crops. Demographic aspects such as age of household head and adult education levels affect only infra-specific diversity of cereals.

Weiss and Briglauer (2002) estimated the impact of household characteristics on the dynamic on-farm diversification in Austria. The study has framed from 1980, 1985, and 1990 period of time and found that the small size of farms are more specialized than large size farms.

#### *2.1.1.2 Indian context*

Basavaraj et al. (2016) explained nature, extent and factors influenced the crop diversification at the micro level in Gadag district in Karnataka. The primary data were collected from 30 sample in 1997, while the secondary data area under major crop groups were obtained to the period from 1998-99 to 2011-12. The results showed the growth rate is higher for area under horticultural crops and pulses as compare to area under cereals, oilseeds, fiber and other crop groups. The estimation revealed that proportion of cereal crop groups has fall down from 32.53 percent to 28.81 percent and that of fruits and vegetables has increased considerably from 0.10 percent to 0.25 percent for fruits and from 4.66 percent to 7.80 percent for vegetables. Further, farm size, gross irrigated area, and net return per farm were the major factors which influenced the crop diversification.

Kumar and Gupta (2015) present the performance of diversity in crops during 1990-91 to 2011-12 in India. Simpson diversification index has shown Indian agriculture system is changing from traditional survival agriculture system to high-value return system but it is not equally distributed across states as well as across different crop sub-sectors. The study also made efforts to know the determinants of crops diversification by using Fixed Effect Model (FEM). The results of FEM have shown that cropping intensity, average annual rainfall, and gross irrigated area to be the key factors of crop diversification. Based on the findings, it argued that policy support in terms of improved cropping intensity, gross irrigated area, insurance coverage, and infrastructure development need to be extended to the farmers.

Dasgupta and Bhaumik (2014) described the role of crop diversification on agriculture growth along with the 'expansion effect' and 'substitution effect' in West Bengal. This study completely used secondary data from 1980-81 to 2009-10. The results revealed that a major change in area under the crops (i.e., boro rice, oilseeds and potatoes) occurred due to substitution effect. The substitution effect has shown significantly negative and stronger than the expansion effect for aus, aman and pulses. However, in the case of fruits and vegetable both substitution and expansion effects have a strong and positive impact.

Kumar et al. (2012) estimated the performance and determinants of crop diversification in four eastern states namely Bihar, Jharkhand, Odisha, and West Bengal of India. Tobit model was applied to find the factors of diversification. The regression outcomes found the technology, level of education, modern implements, and road connectivity has shown significant positive impact on diversification towards higher-return crops. The study also suggested that smallholders have a large interest for cultivation of horticultural crops.

Acharya et al. (2011) tried to explore the nature and degree of "crop diversification in Karnataka". To measure the diversification level Composite Entropy Index (CEI) has been used and results found that diversification level of commercial crops have increased. The factors -infrastructural and technological are negatively related to the level of crop diversification. The adoptions of basic infrastructural facilities (i.e., irrigation, fertilizer, markets, and roads) are raising the process of agricultural development and crop diversification. "The study also found that per capita income, proportion of area under HYVs of cereals, proportion of urban population, share of gross irrigated area, rainfall, average holding size, market density, and fertilizer consumption are the major factors responsible for the changes in crop diversification".

Bhattacharya (2008) has studied the performance of crop diversification in South Asia along with the factors responsible for the crop diversification. The result of Simpson diversity index reveals that countries such as Bangladesh and Bhutan were basically moving toward specialization in food grains whereas countries Nepal, Pakistan, and India slowly moving toward crop diversification. Among South Asian countries Maldives has attained high level of diversification till 1980s but the level of crop diversification has not been increased over time.

Birthal et al. (2007) explained the measures of household participation in cultivation of fruits and vegetables by farm size at the macro level. The study results showed that the diversification of high value crops raise farm incomes, particularly in underdeveloped countries. The results described small holders showed more involvement production in high-value crops mainly fruits and vegetables as compare to larger farm holders.

Joshi et al. (2006) discussed about the factors of agricultural growth and the role of high value crops diversification in India. They found that the growth of wheat and rice production have fall down, and more emphasizes has been given to cultivate of high-value crops. The study authorized that grain-dominated in northern and eastern regions of the country, and found price was the key source of growth. On the other side, in southern and western regions technology was main source of growth in crop income. However, diversification towards high-value crops (i.e., vegetables and fruit) augmented about 27 percent in the 1980s and 31 percent in 1990s.

Mahajan (2004) conducted a study on crop diversification in Kangra. They found that the developed agriculture area is relatively more diversified as compared to less developed area. The factors are responsible for diversification in developed agriculture areas comprise social factors (distance from education, age and number of family member); economic factors (income from farm and non-farm area, tenancy, tractor and farm size) whereas in underdeveloped agriculture areas factors are tenancy, on and off farm revenue, and holding.

Mani and Varadarjan (1985) in their study in India conclude that large farms found more diversify when compared to small farms. Their functional analysis gives the result that diversification leads to diminish the risk associated with farm business.

***2.1.1.3 Punjab specific***

Chhatre et al. (2016) discussed on crop diversification, farmers' decision-making process and risk management in Indian agriculture. The study results indicated that adoption of single wheat-paddy cropping pattern; and incentive of free electricity and overuse of water pumps are key reasons for depletion of ground water in Punjab. They found that risk factors labor, price, credit, and yield risk that might promote crop diversification and reduce dependence on paddy and wheat. The results designated that a portfolio of substitute crops (onion, cauliflower, capsicum and tomato) has higher net expected returns related to the predominant paddy-wheat cropping pattern. This concluded that the alternate cropping pattern is given more surplus production in the market of the same product.

Choudhury et al. (2013) made an attempt on crop diversification and crop water demand analysis by using the remote sensing data and GIS approach in central Punjab. The study suggested that the current cropping pattern adopted by farmers in Jalandhar district of Punjab has directly leads to over exploitation of the ground water and soil of land due to applying high quality of chemical fertilizers. To resolve these problems, they also suggested that at least 40 percent of total agricultural area under wheat-rice pattern should be interchanged by other lower water consuming, high value and soil enriching crops.

Singh et al. (2009) explained the factors influencing economic viability of marginal and small farmers in Punjab. Primary data has been collected from three districts of Punjab Ropar (wheat-maize zone), Ludhiana (wheat-rice zone) and Bathinda (wheat-cotton zone). Discriminant statistical technique has used and results found that off-farm income and rationality in domestic expenditure are the key factors of feasibility of marginal farmers. Therefore, they suggested focus should be given to generate off-farm employment opportunities, assuring remunerative prices and input facilities are need to provide for these farmers.

Kurosaki (2003) presents the performance of crop diversification and specialization empirically for the case of West Punjab. This study has given to more priority of four major crops viz., cotton, rice, sugarcane, and wheat. It is found cropping patterns of survival agriculture changed substantially, more attention given to the crops that have potential of higher value and growing productivity at the aggregate level. These variations reflected comparative advantage and given to the progress in aggregate land production. Ray et al. (2005) explained the crop diversification based on soil and weather requirements of different crops in Punjab using GIS (Geographical Information System). The analysis showed there is a need for diversifying wheat-rice cropping pattern, and need to increase the area under such crops those required fewer inputs and enrich soil health. Further, they analyzed south-western Punjab is appropriate for less water consuming crops (i.e., desi cotton, pearl millet, gram etc.,) whereas north-eastern Punjab is suitable for maize based cropping system. Rice can be replaced by maize and other crops in central Punjab where to control the exploitation of water.

In brief, it was observed that the cropping pattern has been change over time due to changing demand for different food items. It is governed mainly by the agro-ecological and technological factors in a particular area. Overall depiction based on available literature at international level, national level, and state specific shows that till 1980s the trends moved towards cereals particular to wheat and rice. It was mainly because of the advent of green revolution technologies and to meet the domestic demand for staple foods. However from 1990s onwards, relative share in acreage under coarse cereals and pulses have declined and that of fruits and vegetables have increased substantially as a response to integrating the local markets with global markets during post WTO era. But, particularly in Punjab state, area under cereals (wheat and rice) are still larger than others crops.

### 2.1.2 Literature Review on: Determinants of Crop Diversification

#### *2.1.2.1 Global context*

Piedra-Bonilla et al. (2020) explained the role of climate variability on crop diversification categories. The results of probit model show that variability in temperature and precipitation has an impact on each diversification category on same way. The higher variation in climate change lead to higher probability of municipality in very diversified category. Subsequently, intensifying crop diversification could reduce the agricultural risk against extreme climate events.

Asfaw et al. (2018) analyzed the empirical evidence on the adaptation procedure in Niger rural communities. From the estimation, it was found that the household size, accessibility of financial markets, gender, and modern varieties of seeds are positively and significantly associated with both crop and labor diversification.

Thamo et al. (2017) explained the impact of climate variability on agricultural productivity, and also explained how farming system are adapted to suit the new climatic conditions in the western Australian wheat-belt. It was found that profit margins were much more sensitive to climate change than production levels (i.e., yields).

Nguyen et al. (2017) mainly compare the factors that affect farmers' decision regarding the land use choice and crop diversification of rural household. They studied in two different provinces of countries Thailand and Vietnam. A sample size has been collected around 514 farm household in Ha Tinh (Vietnam) and 422 farm household in Ubon Ratchathani (Thailand) in two different years 2007 and 2013. By using fixed effect regression model results found that a livelihood platforms, weather shock, and physical economic condition of the living localities are positively influenced the farmers' land use decision.

Meraner et al. (2015) made an attempt to explore determinants of farm diversification in Netherland by using farm structural survey (FSS) 2011. The study has worked out binary logit model for the determinants of farm diversification in general and multinomial logit model to look out the factors for specific diversification activity. The result of binary logit shows that age, population density and type of soils affect the farm diversification negatively, whereas economic size (measured by Standard output unit), all type of farms (exclude horticulture farms) have positive significant impact on diversification. The result of diversification activity categories (i.e. broadening, deepening and both broadening and deepening) reveals that there is negative impact of age on the entire diversification category where as it is positively affected by family size.

A study has been conducted by (Kasem & Thapa, 2011) on the factors that affecting crop diversification level in Thailand, along with the impact of crop diversification on the farmer's income. The study has taken 245 samples of diversified and non-diversified farmers. The result shows that the large-size farmer prefers mono-cropping pattern while small farmers tried to diversify cropping pattern. Labour shortage, market unavailability, soil suitability, lack of knowledge on growing other crop is some of the factors that restrict large farmers to diversify. Furthermore, outcome of the impact of crop diversification on income reveals that various type of economic benefit is associated with the diversified cropping pattern. It is found that the income level of the farmers has increased who diversified the crops.

A study put forwarded by Rahman (2009) attempted to elaborate the economic determinants of crop diversity in farms of Bangladesh. The 406 sample of farmers in 21 villages have taken. Herfindahl, Margalef and Shannon indices have been used to compute the concentration, richness and evenness of crop, respectively. Logit and OLS have been used to identify the factors that affecting diversity in cropping pattern. The result of regression analysis explicit that likelihood of crop diversification is positively affected by farm size, owner operator, education of farmer, farmer’s membership in NGO’s and developed infrastructure region while it is negatively affected by less developed irrigation facility and decline price of fertilizers and animal power service.

Ashfaq (2008) identified the determinants of farm diversification level in Pakistan. The primary survey based on 200 respondents sample from four villages of Pakistan. They have taken two villages near to the market and two of them away from the market. The results showed main drivers that influenced the diversification level are farm size, age, farming experience, off farm income, road, market, and machinery.

#### *2.1.2.2 Indian context*

Birthal and Hazrana (2019) measured the effects of climate shocks in terms of rainfall-deficit and heat-stress on agricultural productivity. Dynamic panel-data approach has been applied and found that the climate shocks (rainfall-deficit and heat-stress) damage agricultural productivity. From the estimation, it also observed that crop diversification as an important ex ante adaptation measure to cope such climatic shocks.

Birthal et al. (2015) examine the impact of severity droughts on rice production in India. It was found that 1/3rd area under rice crop has been affected by droughts mainly by moderate droughts. The improvement in controlling the adverse effect of weather shocks is mainly the reason of improvements in farmers' adaptations practices and mitigation expansion of irrigation facilities, along with other risk-coping appliance.

The extent of crop diversification is largely based on the geographic climatic characteristics, socio-economic and technological accessibility of a region (Priyadarshini & Abhilash, 2019). A number of factors viz., resources related (i.e., irrigation, climate change, soil health, etc.); technological factors (i.e., seed quality, fertilizer, post-harvest processing, etc.); price factors (i.e., inputs price, output price, profitability, procurement system, import and export, etc.); institutional factors (i.e., size of land, government schemes, density of road, accessibility of market, etc.); and household specific factors (i.e., knowledge, experience, capacity, resources base, food and feed requirement, etc.) are playing an important role to influence the area allocation pattern in a region (Alur & Maheswar, 2018).

Birthal et al. (2014) explained the sensitivity of agriculture sector in India due to climate change. The findings revealed that the variation increase in temperature has negatively impact on agricultural productivity, whereas extreme rainfall has a significant impact but the impact is very small to offset the negative impact of temperature. Further, they found adaptation of irrigation has a potential to save from adverse effect of climate shocks. Moreover, predictions indicate that variations in climate have declined the productivity of agriculture by 25 percent. Agriculture productivity is more impacted by climate shocks in arid and semi-arid regions because of its more sensitive nature in these regions. The loss will be higher in the absence of adaptation.

Kumar and Parikh (2001) assessed the relationship between farm level net-revenue and climate change in India. Further, they explore the effect of annual weather and crop prices on the climate response function. It was observed that the mainly losses in agricultural productivity are causes of climate changes.

Vyas (1996) articulated that the price responsiveness, agro-climatic conditions, technology accessible, market infrastructure, and institutional arrangements for input-output delivery are the major factors of diversification. However, Joshi et al. (2007) suggested that farm diversification is mainly directed by two forces, one is demand side factors; other is supply side factors. Therefore, specific factors observed are credit, irrigation, market infrastructure, road and transport facilities, procurement prices, and government policies on input subsidies.

Gupta and Tewari (1985) made efforts to find out the empirical nexus between crop diversification and socio-economic factors. The study has carried out primary survey of the farmers in villages of Allahabad district for the year 1981-82. The regression result depicts the farm size, market distance, net worth, and rented-in land have negative impact on diversification while intensity of irrigation, price risk, and yield risk negatively affect crop diversification in selected villages.

#### *2.1.2.3 Punjab specific*

Jalota et al. (2014) examined the impact of climate shocks on crop yield, water, and nitrogen-balance. Further, they explore delaying of planting date of crops as adaptation measures. The findings depict that time slice of the 21$^{st}$ century (i.e., mid-century and end-century) climate shocks would increase, as result crop productivity would decrease owing to shortening of crop duration.

Vashisht et al. (2013) estimated the impact of climate change scenario on wheat yield and water productivity. The finding shows that the increased temperature would cause reduction in wheat yield to the extent of 4, 32 and 61 percent in the mid-century periods between 2021-2030, 2031-2040 and 2041-2050, respectively.

From the above discussion, it can be concluded that the farmers' decision about cropping pattern system is depends on various factors viz., natural, man-made, and socio-economic environments factors etc.

### 2.1.3 Literature Review on: Crop Diversification and Economic Efficiency

#### *2.1.3.1 Global context*

Benedetti et al. (2019) analyzed input use efficiency of irrigated crop production and identify its factors, giving special focused on efficient use of water resources. A heteroscedasticity stochastic frontier production model is developed in southern Italy with a sample size of 114 horticultural farms in 2016 dataset collected from the EU farm accountancy data network. The results of the study are found that the most water consuming crops are green beans and pepper. The efficiency scores indicate that these crop farms have less technical efficiency compared to conventional farms. Further, tomato processing farms show highest level of water efficiency (5.01) with greater production level (93,239 kg/ha). Therefore, emphasis should be given to efficient management decisions to minimize water consumption and exploitation, because it is a most crucial resource for agricultural development worldwide.

Mzyece et al. (2018) estimated the impact of crop diversification on technical efficiency and income variability in Zambia. The study has used Rural Agricultural Livelihood Survey for 2012 and 2015, and employs data envelopment approach for efficiency. The estimation found that crop diversification statistically significantly improves income stability but significantly reduces technical efficiency.

Manjunatha et al. (2013) estimated the impact of land fragmentation, farm size, land ownership and crop diversity on farm profit in South India. The results of the frontier model show that there exists inefficiency among different farms. It is observed that the land fragmentation is positively and significantly leads to inefficiency while land ownership and crop diversity is negatively linked with inefficiency. Additionally, it was found that land fragmentation has a significant adverse impact on farm profit. Further, it observed that small land holdings size have lower inefficiencies than larger farm holdings.

Rahman and Rahman (2009) surveyed the impact of land fragmentation on productivity and on technical efficiency in term of rice production in Bangladesh. The estimation of stochastic production frontier function shows that the land fragmentation has a statistically significant harmful effect on productivity and efficiency as expected. It is estimated that the 1 percent change in land fragmentation influenced 0.05 percent rice output and 0.03 percent efficiency. Average of elasticity estimates shows that 1 percent change in family labour and owned draft animal expand technical efficiency by 0.04 percent and 0.03 percent, respectively. Further, they found adoption of new technology improves efficiency by 0.04 percent.

Vedenov et al. (2007) explained the farm efficiency in crop production coffee producing districts in Veracruz, Maxico. The results of stochastic frontier approach indicate that the factors that are responsible to increase production efficiency level are mainly density of population, accessibility ability of road, and higher altitude.

Paul and Nehring (2005) analyzed the economic performance of U.S. farms across farm type, time, region, and farmer characteristics. The deterministic and stochastic frontier methods have been used to measure the scale economies and efficiency of corn-belt farms for 1996-2001. It is found that family farms are scale and technically inefficient. The larger farms are more efficient as compare to small size of farms.

Coelli and Fleming (2004) explained diversification economies and specialization efficiencies in the integrated coffee and food sub-systems. To know whether diversification economies exist and specialization in coffee, they applied stochastic input distance function technique. Results revealed that the substantial technical inefficiency exists, it clearly indicate that there is scope to expand crop production using same amount of inputs resources or improved production technology. Further, it was found that the key drivers that significantly lead to increase technical inefficiency are age of female household head, education level of male household head, whereas the level of family and social obligations are adversely linked with technical inefficiency.

Ahmad et al. (2002) used a primary dataset to capture the inefficiency effects in Pakistan by using stochastic frontier production approach. The results found that the degradation of land resources is due to adaptation of same crop rotations, and prevalence of higher cropping intensity. It is found that the farmers are producing 32 percent less than the target level of potential output.

Llewelyn and Williams (1996) analyzed the technical efficiency for food crop production for irrigated farms in East Java, Indonesia. The non-parametric DEA (data envelopment approach) has been used and found that the farmers are operating inefficiently because of scale inefficiency rather than pure technical inefficiencies. Also, found that "majority of the farmers operate in the region of decreasing return to scale rather than increasing return to scale". Further, it was found that the age, high school education, and diversification cropping activities were found to improve technical efficiency under rainy seasons under irrigated conditions. The analysis shows the farms that use excessive levels of inputs, particularly nitrogen fertilizer are inefficient.

Ali and Chaudhry (1990) explained inter-regional efficiency of crop production in four irrigated cropping regions in Pakistan Punjab. From the estimations of probabilistic frontier production approach found that there is a possibility to raise farmers' income by 13 percent at the same level of resources use. No any statistical significant difference in technical efficiency was found across regions. Further, observed that except in the cotton region the economic efficiency was preform similar across all regions. In cotton region it was lower because of presence of higher allocative efficiency, which is attributable to the more dynamic production technologies being adopted in that region.

***2.1.3.2 Indian context***

Shanmugam and Venkataramani (2006) estimated the technical efficiency and its determinants for 1990-91 across districts in India. For the analysis data has been collected from CMIE (1993) and CMIIE (2000) for 248 districts across 12 major states. The results of the stochastic frontier production function shows that Indian districts have a mean technical efficiency of 79 percent, showing that, on an average agricultural output can be increased by about 21 percent with the given or available resources. Further, they estimate the determinants of the technical efficiency and found that health, education, and infrastructure are significant determinants of the technical efficiency. The findings of the study suggest that the only improve to technical efficiency are not one-size-fits-all. Indeed, even districts within the same state would benefit differently from the same set of interferences. In that sense, it might be wise to implement policy interventions from more ground level.

Parikh et al. (1995) made an attempt on two distinct approaches such as behavioral and stochastic cost frontier is used to measures farms cost inefficiency. Stochastic frontier approach is used for inefficiencies scores. Data on household composition, farm production, inputs prices and costs were collected to 436 farms in 1990-91. The major crops are selected for analysis primarily, wheat (38%), maize (24%), sugarcane (22%) and vegetables in Peshawar (Pakistan). The findings suggest that the small size of holdings seems to be more efficient as compare to the large land holdings size in the region.

Chavas and Aliber (1993) enlightened a non-parametric method to the measurement of four type of efficiencies in agriculture production viz., technical, allocative, scale and scope efficiencies. The model is applied on the observation 545 in 1987 of Wisconsin farms. The estimation of the study found that economic losses are largely produced by allocative and scale inefficiencies. The study proposes that almost farms tries to find out the path of improving their production process. Further, finding shows that economies of scale exist with small land holding farms and some diseconomies of scale are found for the large land holding farms.

#### *2.1.3.3 Punjab specific*

Singh et al. (2017) analyzed crop-wise resources use efficiency across farm-size in Punjab; and identifies its determinants by using plot-level cost of cultivation survey (CCS) data of principal crops from 2008-09 to 2010-11. The two-step approach has been developed, in the first step DEA technique was employed to measures technical efficiency, in the second step, Tobit regression has been work out to find the various factors to explain the variation in technical efficiency. The results revealed that the larger farm size holding are more technical efficient than the small holding size all selected crops. Further, it is found that the large farm size has used higher utilization of machine and fertilizer per hectare and relatively less use of labour. Conversely, the marginal and smallholding size farmers have applied more irrigation hours per hectare than the medium and large farm size farmers. Therefore, overall findings suggest that emphasis should be given to enhance the operational land holding size with the help of consolidation. Moreover, the also identify that there is a positive and significant association between farm size and number of schooling. However, age, number of schooling, diversification index and bio-abiotic stress have negatively impact with technical efficiency. The average improvement in technical efficiency is probable as 26.95, 24.02, and 7.26 percent in favour of cotton, paddy and wheat respectively deprived of increasing the input use.

Sekhon et al. (2010) studied the technical efficiency in crop production in Punjab state to know how different zones have adopted the modern technology. Primary data has been collected through three-stage stratified random sampling technique in 2005-06. The state divided into three zones; sub-mountainous zone (9%), central plain zone (65%), and south-western zone (26%). The 300 sample size covered (100 marginal, 100 small, and 100 other categories) of farmers. The specific stochastic frontier production function has been estimated to find the technical efficiency of individual farm. The results of the study found that even though Punjab is agriculture rich state but still there is need to improve technical efficiency of the farms. The technical efficiency has revealed a large variation across zones; the central zone has been found most efficient 90 percent than south western and sub-mountainous. Further, the results of production function explained that the existence of disguised unemployment in sub-mountainous region.

Javed et al. (2008) estimated the economic efficiencies of production of rice-wheat pattern and also identify its determinants in Pakistan, Punjab. Two steps DEA and Tobit model approach has been estimated to measure the efficiencies scores and Tobit model for identify its determinants. The model has been applied on the 200 observation in 2005-06 by using multistage random sampling technique. It is found that the average scores of the technical efficiency is 0.83, allocative efficiency is 0.44 and economic efficiency is 0.40 percent respectively. The small size of land holding farmers are more efficient in technical efficiency than the large holdings. But, both size of holdings farms are allocative and economic inefficient. Further, Tobit estimation indicate that the farm size, age, year of schooling, number of contacts with extension agents, credit and market distance are the powerful drivers of technical efficiency, on the other side year of schooling, number of contracts with extension agents, and access to credit has significant impact on allocative and economic inefficiencies.

Sidhu (1974) has followed the L-Y model to compare the economic efficiency of old versus new verities of wheat in Punjab from 1967-68 to 1970-71. They compare economic efficiency and price efficiency of small and large; and tractor and non-tractor operated wheat farms. The cobb-Douglas function, profit function and labour demand function are used to estimate efficiency of wheat production. The results of the cobb-Douglas production function revealed that the new wheat varieties are economically more efficient as compare to the old wheat by 48.50 percent. Further they found that there are no difference between in efficiency parameters, small and large farms have perform equal in technical efficiency and relative price efficiency. They found that tractor operated wheat farms have same economic performance as non-tractor operated farms. Similarly, the large farms are no better off than small farms. It is pointed that the small and large farmers have the same degree of economic motivation appears to hold.

### 2.1.4 Issues and Research Gap

After rigorous review of the existing literature on crop diversification, some significant observation can be made. Earlier studies that are carried out in different regions across the globe, recalls crop diversification as an increasing phenomenon and a popular policy prescription towards the goal of increasing income of small holders. Various estimations of empirical studies are different substantially on the basis of selection of crops, time period, methodology, etc. and thus offer different conclusions.

In India, majority of the literatures have examined the nature and degree of crop diversification either at aggregate level (country/state/district/regional) or at farm or household level. Studies focusing crop diversification behavior at particular state Punjab is less, and all the existing studies have growing interest to measured crop diversification behavior by using different statistical tools such as Herfindahl Index, Composite Entropy Index, Gibbs and Martin Index, and many more, however none of the study has used 'Kendall's Coefficient of Concordance Index'/'Rank Analysis' for the inter temporal movements. Therefore, present study pursues the research method which has not been applied in the existing literature. Further, the earlier studies are mainly confined to time period of 20-25 years to trace the diversification patterns in the state. This study contributes to the literature by extending the time period of 58 years from 1960-61 to 2017-18.

Further, this study contributes to the literature by addressing the issue of impact of weather shocks on crop productivity at Punjab state at district level. This was one of less emphasized issues in available literature. Therefore, the present study not only incorporates this issue but further enables to identify the micro level problems of farm sector followed by appropriate policy formulations to resolve them also.

In addition, several empirical studies have provided prominent works on technical production efficiency. However, an important aspect, that received little attention in the empirical literature, is related to the decomposition analysis of production efficiency. From this perspective, the present study contributes to the literature as it applies decomposition analysis of technical efficiency across regions. This decomposition analysis of efficiency intends to provide the sources of efficiencies or inefficiencies among different farms. Similarly, there is the dearth of studies that could recommend the amount of input reduction in order to increase output across regions of Punjab. In this backdrop, the present analysis throw lights on the slacks and the targets setting appliance to evaluate the way for improvement in the context of inefficient tehsils. Thereby, this study, under this analysis, explains how much proportion of each input has to be reduced for each inefficient tehsil to attain the same output. This analysis assists to withdraw those inputs which are used in unreasonably in the production process.

# Chapter-3

# A Temporal Analysis of Crop Diversification in Punjab's Agriculture

# CHAPTER-3

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## 3.1 Introduction

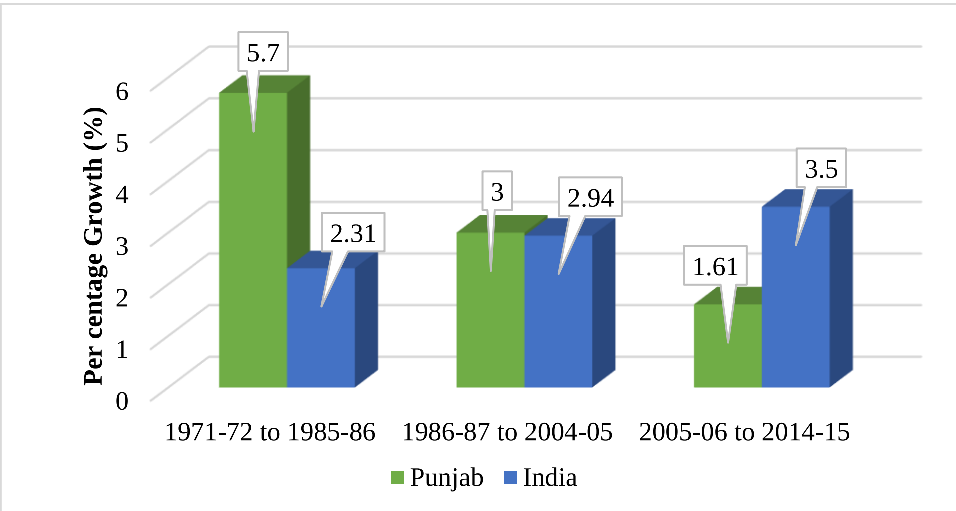
The emergence of green revolution in developing countries during 1960s' has given rise to conventional agricultural system. The farmers applied excessive synthetic inputs such as chemical fertilizers, insecticides, fungicides and pesticides to increase in productivity and profitability on the farms (Eicher, 2003). This highly commercialized agriculture system has replaced with mono-cropping system instead of traditional diversified cropping system in developing countries (Hutagaol, 2006). As result several serious distortions has arisen in the economy (Sajjad & Prasad, 2014). Recently, there is growing concern among researchers about the ill effects of conventional agricultural production system in developing nations (Chand, 1999; Sidhu, 2002; Singh, 2004; Singh & Sidhu, 2004; Ray et al., 2005; Sharma et al., 2005; Ghosh et al., 2015; Singh, 2015).

A number of studies proposed that crop diversification is an appropriate strategy to neutralize these challenges and hurdles faced by developing nations (Mahmud et al., 1994; Rahman, 2009; Kasem & Thapa, 2011; Michler & Josephson, 2017). As per Food and Agriculture Organization (FAO, 2012) crop diversification is an effective method to deal with the issues of nutrition security, ecological management, employment generation, poverty alleviation and sustainable agricultural growth. Similarly, International Food Policy Research Institute and many other studies have also supported the above argument that higher growth in agricultural income can be achieved by crop diversification (Vyas, 1996; Joshi et al., 2004, Joshi et al., 2006; Taffesse et al., 2011).

Indian agriculture in general and Punjab's agriculture in particular, is dealing with the complexity originated from practicing conventional agriculture system (Ghosh et al., 2015). Due to pursuance of conventional agricultural practices, more than 3/4$^{th}$ of the cultivated area faces the problem of water table deficit (Hira et al., 2004; Sarkar, 2011). Additionally, around 2.23 lakh hectares land area out of 50.36 lakh hectares is facing various soil related issues (Punjab State Land Use Board, 2015).

Undoubtedly, the state has achieved a spectacular performance in agriculture. The state's agricultural GDP growth rate was 5.7 percent per annum from 1971-72 to 1985-86, which was much greater as compared to the national agricultural growth rate, which stood at about 2.31 percent per annum. However, during 1985-86 to 2004-05 Punjab's economy started to lag with growth rate touching 3 percent per annum (Figure 3.1). During 2005-06 to 2014-15, it further slides down to only 1.6 percent per annum as against 3.5 percent per annum at all India level. Thus, to overcome such kind of challenges focus has to be shifted towards changing the cropping pattern in the state.

**Figure 3.1:** Growth rate of agriculture in Punjab and India




*Source:* Gulati et al. (2015)

Several policy makers and researchers have given emphasis on this falling phase of agricultural productivity in Punjab, and they tried to explored extent and degree of diversification in agriculture and sources of its growth (Kurosaki, 2003; Kumar & Gupta, 2015; Das & Mili, 2012; Dasgupta & Bhaumik, 2014; Banerjee & Banerjee, 2015; Basavaraj et al., 2016). However, still state farmers are facing various difficult phases such as falling productivity growth, environment degradation due to conventional practices. Even-though the government continuously strives for various crop diversification policies, yet serious steps have not been taken to preserve state's natural resources which are degraded by commercial agricultural system. Being a small and one of the agriculturally rich state, it is important to resolve such serious matter. A number of studies have been conducted on this issue; but an important aspect that has received; little attention is the decomposition analysis of sources of agriculture growth. As noted above, the present study put an effort in this direction. This chapter proposes to fill this gap by focusing on decomposition analysis to know the sources which are responsible for this change in growth.

In this chapter, the time-series dataset is used from 1960-61 to 2017-18 collected from DES (Directorate of Economics and Statistics) of India and Economic and Politically Weekly Research Foundation. This study has followed the well-developed approaches (Boyle & McCarthy, 1997)[1] and (Dhindsa & Sharma, 1995)[2] for the analysis of performance of cropping pattern in state. The questions that arise in this chapter are:- What are the recent trend followed in farming sector by farmers in Punjab?; Are they specilazing in a few crops or diversified?. Therefore, this chapter of the study focuses on (i) to explore the trend and pattern of crop diversification in Punjab, and (ii) to identify the factors those determine crop diversification.

[1] This approach is used for inter-temporal movements of crops.

[2] This is followed for explore the sources of change in patterns (Decomoposition Approach).

This study contributes to the literature in following way. Firstly, it assess the decomposition analysis to compute the major sources of agrarian growth in the state which will further help in making appropriate policies to increase agricultural growth rate in the state. Secondly, it pursue a new methodology which has not been utilized in the literature before. All the existing studies had growing interest in the statistical tools to measure degree of diversification. The present study applied the Kendall's Coefficient of Concordance Index in order to test the degree of consistency or concordance between the ranks of the crops in different years. The main purpose to use rank of the area under crops is to identify the top performing crops in a competitive farming.

The remaining of the chapter is structured as follows. Section 3.2 provides the factual background in terms of relevant descriptive statistics. Section 3.3 represents the sources of data and empirical methodology framework. Section 3.4 presents the main results; while the last Section 3.6 presents conclusions and policy implications.

## 3.2 Background and Literature

Various studies are available on the importance of diversification in the agriculture sector. Generally, in literature diversification has divided into two parts:-vertical diversification and horizontal diversification. The vertical diversification refers to diversification between agricultural and allied activities whereas horizontal diversification means a mix or adds on of more crops to the existing pattern (Haque et al., 2010; Banerjee & Banerjee, 2015; Chakrabarty, 2015). A number of studies have shown that the agricultural sector has gradually diversified from low value to higher value return crops. The countries like Sri Lanka, India, South Asia, and others have achieved better food security at the national level based on their comparative advantage in producing primary products; and have specialized in the production of either rice, wheat or maize. Nepal, Bhutan, and Pakistan have shown lower diversity because these countries still have a deficit in food-grain production, forcing them to concentrate on the cereals, particularly rice, maize, and wheat to achieve their goal of self-sufficiency in food grains, while the country Bangladesh has attained their self-sufficiency condition in food grain but they still concentrate on only rice crop (Joshi et al., 2004, Rahman, 2009; Mahmud et al., 1994; Mermut, 2012). Studies which have particularly examined the change in cropping pattern in Indian context point out that the highest proportion of food grain to the total cropped area is in the north-east region, north-west region, east region, and central region, while the southern region is the leader in production of non-food grain crops (Kumar & Gupta, 2015). The structure of crop diversification in Indian agriculture has rapidly changed after green revolution. The state of Karnataka has higher crop diversification in agriculture followed by J&K, Uttarakhand, Rajasthan, Maharashtra, Uttar Pradesh, Andhra Pradesh, Madhya Pradesh, and Tamil Nadu. The states like Chhattisgarh, Tripura, and Odisha have been observed among the less crop diversified states. The northern dry zone is more diversified than the northern transitional zone. The prevailing institutional structure in these states has ensured that the government price and trade policies are powerful key to influence the changing cropping pattern conditions in different states (Kalaiselvi, 2012; Rao et al., 2006; Roy & Thorat, 2008). Further, the studies which have examined within country changes in cropping pattern have shown that the cropping pattern had changed from a subsistence level to commercial level. The states like West Bengal, Gujarat, Punjab and West Punjab have shown a weakening trend in the area under cultivation of pulses whereas an increase area under cultivation of the higher return value crops such as cereals rice, wheat etc. (Shiyani & Pandya, 1998; Singh & Sidhu, 2004; Kurosaki, 2003; Sharma, 2005; Acharya et al., 2011; Chakraborty, 2012; Dasgupta & Bhaumik, 2014; Sajjad & Prasad, 2014). Meanwhile, the state of Karnataka has shown an expansion in area under cultivation of horticultural crops and pulses as compared to oilseeds, cereals, fibre and other crop groups (Basavaraj et al., 2016).

### 3.3 Material and Method

Secondary data have been used to explain the cropping pattern and consistency of the crops. Data has been collected on Area (000' ha), Production (000' tone), and Yield (kg/ha) from Directorate of Economics and Statistics (DES) of India and data on Farm Harvest Price (Rs. in per Quintal) from Economic and Political Weekly Research Foundation (EPWRF). Further, the data on the variables such as fertilizers per hectare (NPK), number of market per hectare (MARKT), road length in Kms. per hectare (ROAD), percentage of urban population (UB), number of tractor per hectare (TRC), rainfall in mm (RAIN), cropping intensity (CI), and intensity of irrigation (IRRINTY) have been collected from VDSA (Village Dynamics in South Asia) dataset generated by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The absolute value of considered variables in the study is transform in terms of natural logarithm. One of the reasons behind selection of data from 1960-61 onwards is due to the emergence of various structural transformations such as green revolution in that decade. For the temporal analysis data has structured for the variables viz., area, production and yield under leading crops. This study concentrations on major 11 crops, viz., wheat, maize, cotton, paddy, total oilseeds, sugarcane, potatoes, total pulses, barley, onion, and millets (Bajra); together accounting for 93 per cent of the total cropped area.

#### *3.3.1 Exponential growth rate and quadratic growth rate*

To evaluate the growth rate both exponential form of growth rate and quadratic form of growth rate has computed. The exponential form is chosen because this gives a constant rate of increase or decrease per unit of time. The initial form of exponential function can be written as:

$$Y_t = AB^t v_t \qquad (3.1)$$

For convenient, the multiplicative form of the model has been transformed into additive form by taking natural logarithmic and the final form Equation (3.1) is as follows:

$$y_t = a + t.b + u_t \qquad (3.2)$$

where $y_t = \log$ of $area, production,\ and\ yield$

a = intercept

t = time (in year)

$u_t$ = error term and a is the intercept

here, b gives the instantaneous (at a point in time) growth rate and not the compound (over time) growth rate. Therefore, the compound growth rate is calculated using the following formula:

*Compound Growth Rate (CGR) = Antilog (b -1)×100*

In exponential form assumes constant growth rate, thus it is hard to determine any acceleration or deceleration in the growth rate over time. To overcome this problem log-quadratic form is used. The log-quadratic form can be written as follows:

$$y_t = a + bt + ct^2 + u_t \qquad (3.3)$$

If the estimated value of *c* has significantly (t-ratio is used as test statistics) positive value, it will depict acceleration in growth rate and in case of significantly negative value that will indicate deceleration in growth rate. The combination of $t$ and $t^2$ on the right-hand side of Equation *(3.3)* may generate a problem of multi-collinearity. This problem is avoided by the normalization of time in mean deviation using the average mean of time, by setting *t = 1,2,3…….*which allows the time *(t)* and its square *($t^2$)* to become orthogonal.

To know the magnitude of crop diversification, there are number of statistical tools by which diversification can be measured such as Simpson Index, Entropy Index, Modified Entropy Index and many more; and each of these indices have its own limitations (Shiyani & Pandya, 1998). In spite of their differences, these indices give more or less similar results. In this chapter Herfindahl Index (HHI)[3] and Composite Entropy Index (CEI)[4] (Indices are computed based on the share of area under crop to gross cropped area) have been computed to measures of diversification. HHI has more frequently applied for estimation because of its simplicity in computation, whereas CEI applied because it possess all the desirable properties and also fulfill all the limitation of other indices. Since the index uses $-log_N P_i$ as weights, it gives higher weights to lower quantity and less weight to higher quantity (Khatun & Roy, 2015).

### *3.3.2 Rank analysis*

Further, to study the pattern of the crops according to the ranks of their area covered over the period of time, crops are ranked in descending order. In order to test the degree of consistency or concordance between the rankings of the crops in different years, Kendall's coefficient of concordance[5] has been worked out which is denoted by the symbol *'W'*, it is a non-parametric statistic. It is widely used to find out the degree of association among several *k* (here *k* is time period) sets of ranking of *n* objects or individuals (*n* is number of crops). The *'W'* statistics value in Equation (3.4) examine the consistency of ranking of crops over the years where *k* is the number of raters (58 years from 1960- 61 to 2017-18), n is the number of

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[3] Herfindahl Index (HHI) is computed as: $HHI = \sum_{i=1}^{n}\left(\frac{P_i}{\sum_{i=1}^{n}P_i}\right)^2$ where, $n$ is the total number of crops and $P_i$ represents area proportion of the $i^{th}$ crop in total cropped area. HHI is bounded by zero and one. When it takes value one means there is complete concentration and approaches zero indicate diversification is perfect. Former this index was applied by Sharma (2005).

[4] Composite Entropy Index (CEI) = $-(\sum_{i=1}^{N} P * log_N P_i) * \{1-(1/N)\}$ since index uses $-log_N P_i$ as weights, it assign more to lower quantity and less weight to higher quantity. HHI index is a measure of concentration but CEI is diversification Index.

[5] Kendall (1984), The problem of m rankings statistics: Theory and Practice, 133-135.

individuals or objects (here the number of crops 11). If there are two set of rankings than it normally employ Spearman's coefficient of correlation, but if there are more sets of rankings, Kendall's coefficient of concordance have to used. Kendall's *W* ranges from $0 \leq W \leq 1$, where *1* represents perfect concordance or complete agreement, *0* represents no agreement. Kendall's coefficient of concordance can be computed as follows.

$$W = \frac{12s}{k^2(n^3-n)} \qquad (3.4)$$

where, $S = \sum_{i=1}^{n} \sum (R_{i-}\bar{R})^{2}$

*S* is the sum of squares of the deviations of sum of ranks of crops *(Ri)* from the mean of the ranks $\bar{R}$. ($\bar{R}$ = *k (n + l)/2*) Then the coefficient of concordance *(W)* was worked out from the *S* as follows.

### *3.3.3 Index of rank concordance*

The inter-temporal mobility of ranking of crops has construct by using rank concordance index proposed by Boyle and McCarthy (1997). This estimate tries to capture the change in the rankings as reflected by Kendall's index of rank concordance. In particular, they proposed a multi-annual version *(RCt)* and a binary version *(RCat)* of the measure. Multiannual version is defined as follows:

$$RC_t = \frac{Var[\sum_{t=0}^{\tau} R(Y_{it})]}{Var[(T+1)^{*} R(Y)_{i0}]} \qquad (3.5)$$

In Equation (3.5), $R(Y)_{it}$ = Actual ranking of the $i^{th}$ crop area in total area under all crops in year *t;* $R(Y)_{i0}$ = Actual ranking of the $i^{th}$ crop area in the initial year *0* in terms of total area under all crops; *(T+1)* = Number of years for which data are used in calculating the index.

The binary measure, on the other hand can be obtained by considering the ranks in year *t* and *0* is given as follows:

$$RC_{at} = \frac{Var[R(Y)_{it} + R(Y)_{i0}]}{Var[2^{*}R(Y)_{i0}]}$$

*(3.6)*

Clearly, the multi-annual measure, extending over the entire period, contains all possible pairs of years for which the binary measure could be computed.

*3.3.4 Decomposition of sources of growth*

Since the green revolution period, cropping pattern has been changing in agriculture because of changes in its sources of growth. In this regard, there is a need to compute the major sources of agrarian growth in the state which would further help in making appropriate policies to increase agricultural growth rate in the state. Many researchers have used decomposition analysis to recognise the major sources of agriculture growth. In the literature, broadly two versions of decomposition methods have been debated: first is additive version of decomposition and second is multiplicative version of decomposition. A systematic approach to study the decomposition of agricultural growth was initially given by (Minhas & Vaidyanathan, 1965) who followed additive version of decomposition. They considered change in total production of agriculture pertaining to changes in four aspects which were area, yield, cropping pattern and interactions among the later two. However, as (Sagar, 1980) extended the "decomposition to seven component form, which included decomposing agricultural output at prevailing prices into three components, viz,. area, yield, price and their interactions (Area-Price, Area-Yield, Yield-Price and Area-Price-Yield)." In this study factor additive version of decomposition analysis; is used to find the total change in agricultural production over time, formerly this method applied in Punjab by (Dhindsa & Sharma, 1995).

$Q_t - Q_0 = A_t \sum C_{it} Y_{it} P_{it} - A_0 \sum C_{i0} Y_{i0} P_{i0}$ ***or***

$$\Delta Q = Q_t - Q_0 = (A_t - A_0) \sum C_{i0} Y_{i0} P_i + A_0 \sum C_{i0} (Y_{it} - Y_{i0}) P_i + A_0 \sum (C_{it} - C_{i0}) Y_{i0} P_i$$
$$+ (A_t - A_0) \sum (C_{it} - C_{i0}) Y_{i0} P_i + (A_t - A_0) \sum C_{i0} (Y_{it} - Y_{i0}) P_i$$
$$+ A_0 \sum (C_{it} - C_{i0}) (Y_{it} - Y_{i0}) P_i + (A_t - A_0) \sum (C_{it} - C_{i0}) (Y_{it} - Y_{i0}) P_i$$

*(3.7)*

In Equation (3.7), $Q_0 = \mathrm{A}_0 \sum \mathrm{C}_{\mathrm{i}0} \mathrm{Y}_{\mathrm{i}0} \mathrm{P}_{\mathrm{i}0}$ $and$ $Q_t = A_t \sum C_{it} Y_{it} P_{it}$ presents the total value of agricultural output (at constant prices $P_i$) of initial and final period correspondingly. $A_0$ and $A_t$ are total cropped areas in the initial and final year respectively. $C_{i0} = \left(A_{i0}/_{A_0}\right), C_{it} = \left(A_{it}/_{A_t}\right)$ and $Y_{i0}$, $Y_{it}$ denote the share of area under each crop to total cropped area and yield of ($i^{th}$) crop in the initial and current year respectively. $P_i$ are base year farm harvest price. Here, $(A_t - A_0) \sum C_{i0} Y_{i0} P_i$ represent the simply area effect; $A_0 \sum C_{i0} (Y_{it} - Y_{i0}) P_i$ is yield effect; $A_0 \sum (C_{it} - C_{i0}) Y_{i0} P_i$ represent cropping pattern effect. $(A_t - A_0) \sum (C_{it} - C_{i0}) Y_{i0} P_i$ is represent area and cropping pattern effect; $(A_t - A_0) \sum C_{i0} (Y_{it} - Y_{i0}) P_i$ represent area and yield effect; $A_0 \sum (C_{it} - C_{i0}) (Y_{it} - Y_{i0}) P_i$ represent cropping pattern and yield effect. $(A_t - A_0) \sum (C_{it} - C_{i0}) (Y_{it} - Y_{i0}) P_i$ is area, yield and cropping pattern.

### *3.3.5 Determinants of crop diversification*

To determine the factors the factors those affect crop diversification following specification (Deschenes & Greenstone, 2007) is applied:

$$Y_{it} = \alpha_i + \sum_{i=1}^{N} \rho_i (a_i \times T) + \sum_{j=1}^{M} \beta_j x_{it} + + \varepsilon_{it}$$

*(3.8)*

where, $Y_{it}$ is log of crop diversification in district $i$ in year $t$. $\alpha_i$ represents the district fixed effect. Further, $(a_i \times T)$ is a district-specific exponential time trend to switch for the district-specific heterogeneity in crop diversification due to others technological change. $\rho_i$ is coefficient of time trend across districts. The $\beta$*'s* are coefficients of different $x_{it}$ explanatory variables in districts *i* in year *t.*

### *3.3.6 Measures of crop diversification*

Several indices have been used to measures the diversity in cropping system such as Herfindahl Index, Simpson Index, Entropy Index and many more. Each index have its own merits and demerits. In spite of their differences, these indices give more or less similar results. In this study, Composite Entropy Index has been constructed as earlier followed by (Shiyani & Pandya, 1998).

$$CEI_{it} = -\left(\sum_{i=1}^{N} P * log_N P_i\right) * \{1 - (1/N)\}$$

*(3.9)*

where, $CEI_{it}$ is the diversity in cropping system; $p_i$ is the area share of crop $i$ in the total cropped area. The range of the index lies between 0 & 1; 0 represents complete specialization, whereas 1 represents complete diversification. Since index uses -$log_N P_i$ as weights, it assign more to lower quantity and less weight to higher quantity.

## 3.4 Results

### *3.4.1 Shift in cropping pattern*

The cropping pattern in Punjab has changed; if the area under cultivation of the crops is seen over time. Throughout the study period, most of the crops have lost their area under cultivation except for wheat and paddy. Table 3.1 represents the shift in cropping pattern in

Punjab. The results show that share of area under wheat to total cropped area has increased from 30.26 percent in 1960-61 to 44.07 percent in 2017-18. Paddy, which consisted of only 4.80 percent of total cropped area in 1960-61 has been able to augment its share to 36 per cent in 2017-18. The area under both these crops have expanded at the cost of the area under crops such as maize, cotton, oilseed, sugarcane, millets, pulses, etc. The share of area under pulses has drastically reduced from 55.05 percent in 1960-61 to a negligible 0.37 percent in 2017-18. The area under cotton in 1960-61 was 9.45 percent of the total cropped area, which has declined 2.24 percent in 2017-18. The area under cotton has shown remarkable fluctuation during the study period, which may be the consequence of pest attack, problem of water logging in the cotton belt and adoption of Bt cotton in latter period. The total cropped area has augmented from 47.32 lakh hectare in 1960-61 to 78.96 lakh hectare in 2017-18. But, this expansion in area was limited to wheat and paddy crops only. Thus, the increase in the area and production of cereals has grown at a faster rate after 1966-67, whereas, the reverse trend is observed in the case of pulses. The continuous decline in the area under the pulses took place at the expense of increase in the area under cereals, particularly of wheat and paddy.

**Table 3.1:** Proportion of area under each crop to total cropped area in Punjab (000' hectare)

| Year | Wheat | Paddy | Cotton | Maize | SUG | TOS | Potatoes | TP | Barley | Onion | Millet |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1960-61 | 25.79 | 4.09 | 8.05 | 5.89 | 3.33 | 0.14 | 2.40 | 46.92 | 1.15 | 0.00 | 2.23 |
| 1965-66 | 40.28 | 7.31 | 10.77 | 9.60 | 5.84 | 0.37 | 4.17 | 16.09 | 1.67 | 0.01 | 3.89 |
| 1970-71 | 47.58 | 8.07 | 9.83 | 11.49 | 6.11 | 0.23 | 2.65 | 8.57 | 1.18 | 0.02 | 4.28 |
| 1975-76 | 45.36 | 10.55 | 10.36 | 10.73 | 5.88 | 1.18 | 2.12 | 8.15 | 2.23 | 0.07 | 3.38 |
| 1980-81 | 47.79 | 20.02 | 11.61 | 6.42 | 4.21 | 0.67 | 1.21 | 5.74 | 1.10 | 0.02 | 1.21 |
| 1985-86 | 49.46 | 27.24 | 9.01 | 4.13 | 3.36 | 0.68 | 1.23 | 3.57 | 0.79 | 0.02 | 0.49 |
| 1990-91 | 49.81 | 30.67 | 10.05 | 2.88 | 1.64 | 0.39 | 1.54 | 2.27 | 0.56 | 0.03 | 0.17 |
| 1995-96 | 46.96 | 31.86 | 10.82 | 2.49 | 3.00 | 0.57 | 1.98 | 1.59 | 0.58 | 0.02 | 0.12 |
| 2000-01 | 47.62 | 36.49 | 8.48 | 2.31 | 1.21 | 0.83 | 1.69 | 0.84 | 0.45 | 0.02 | 0.07 |
| 2005-06 | 48.37 | 36.85 | 8.47 | 2.06 | 1.14 | 1.05 | 1.17 | 0.45 | 0.26 | 0.11 | 0.07 |
| 2010-11 | 48.31 | 38.96 | 7.71 | 1.83 | 0.74 | 0.89 | 0.96 | 0.29 | 0.17 | 0.11 | 0.04 |
| 2015-16 | 48.44 | 41.08 | 3.94 | 1.59 | 0.60 | 2.25 | 1.24 | 0.62 | 0.12 | 0.12 | 0.00 |
| 2017-18 | 49.45 | 40.43 | 2.52 | 2.34 | 0.54 | 2.87 | 1.17 | 0.42 | 0.11 | 0.12 | 0.03 |

*Source:* Author's Calculation by using data from Directorate of Economics and Statistics

Note: SUG= Sugarcane, TOS=Total Oil Seeds, TP = Total Pulses

*3.4.2 Exponential and quadratic growth rate*

Table 3.2 presents the exponential growth along with acceleration and deceleration growth in area, production, and productivity of the crops. It found that only wheat, paddy, potato, and onion crops have experienced positive exponential growth under area, while all other crops have shown negative exponential growth rate during the study period. Further, results show that agricultural sector is affected by deceleration in area, production and productivity growth. This deceleration in growth occurs due to pursuing monocropping pattern. The results are found to be similar as reported by Singh et al. (1998); Sidhu and Johl (2002) in their studies. Expansion of irrigation facilities, new technology, risks in cultivation of the other perishable crops, low productivity and market performance, low yields in pulses and unsatisfactory prices are found to be the factors responsible for the emergence of monocroping as major structural change in the state (Deshpande & Chandrashekar, 1982; Grewal & Bhullar, 1982).

**Table 3.2:** Exponential growth with acceleration or deceleration

| Crops | Exponential growth in Area | Acceleration/ Deceleration | Exponential growth in production | Acceleration/ Deceleration | Exponential growth in Productivity | Acceleration/ Deceleration |
|---|---|---|---|---|---|---|
| Wheat | 1.3975 | -0.0005 | 3.8140 | -0.0010 | 2.2157 | -0.0005 |
| Paddy | 4.9628 | -0.0011 | 7.3599 | -0.0018 | 2.3943 | -0.0008 |
| Cotton | -0.4618 | -0.0007 | 1.2631 | -0.0005 | 1.4293 | 0.0001 |
| Maize | -2.7837 | -0.0001 | -0.8023 | 0.0002 | 2.0309 | 0.0003 |
| TOS | -3.4560 | -0.0009 | -2.3774 | -0.0008 | 1.6060 | -0.0001 |
| Potatoes | 4.1514 | -0.0001 | 5.1153 | -0.0002 | -1.2597 | -0.0013 |
| SUG | -0.6715 | 0.0001 | 0.5746 | -0.0012 | 1.2935 | -0.0003 |
| TP | -7.0541 | 0.0006 | -7.6703 | 0.0000 | 0.6140 | 0.0003 |
| Barley | -3.8446 | -0.0009 | -0.6557 | -0.0014 | 3.0264 | -0.0005 |
| Onion | 6.0643 | -0.0003 | 9.1091 | -0.0004 | 1.1926 | -0.0001 |
| Bajra | -9.5396 | -0.0004 | -8.9002 | -0.0012 | 0.6920 | -0.0005 |

*Sources:* Author's Calculation,
Note: TOS=Total Oil Seeds, SUG= Sugarcane, TP = Total Pulses

### *3.4.3 Estimation of crop diversification index*

Table 3.3 presents the degree of crops diversification over time. It implies that the trends have moved towards specialization in favour of wheat and paddy crops.

**Table 3.3:** Crop diversification measures in Punjab

| Years | Concentration | Diversification Index | Years | Concentration | Diversification Index |
|---|---|---|---|---|---|
| | HHI | CEI | | HHI | CEI |
| 1960-61 | 0.30 | 0.59 | 1989-90 | 0.35 | 0.51 |
| 1961-62 | 0.28 | 0.61 | 1990-91 | 0.35 | 0.50 |
| 1962-63 | 0.27 | 0.61 | 1991-92 | 0.35 | 0.51 |
| 1963-64 | 0.27 | 0.61 | 1992-93 | 0.36 | 0.50 |
| 1964-65 | 0.22 | 0.69 | 1993-94 | 0.36 | 0.49 |
| 1965-66 | 0.22 | 0.69 | 1994-95 | 0.35 | 0.50 |
| 1966-67 | 0.22 | 0.70 | 1995-96 | 0.34 | 0.52 |
| 1967-68 | 0.24 | 0.68 | 1996-97 | 0.33 | 0.52 |
| 1968-69 | 0.27 | 0.66 | 1997-98 | 0.35 | 0.50 |
| 1969-70 | 0.26 | 0.66 | 1998-99 | 0.37 | 0.48 |
| 1970-71 | 0.27 | 0.65 | 1999-00 | 0.38 | 0.47 |
| 1971-72 | 0.28 | 0.64 | 2000-01 | 0.37 | 0.47 |
| 1972-73 | 0.28 | 0.64 | 2001-02 | 0.38 | 0.46 |
| 1973-74 | 0.25 | 0.67 | 2002-03 | 0.38 | 0.47 |
| 1974-75 | 0.24 | 0.69 | 2003-04 | 0.38 | 0.46 |
| 1975-76 | 0.25 | 0.67 | 2004-05 | 0.38 | 0.46 |
| 1976-77 | 0.27 | 0.65 | 2005-06 | 0.38 | 0.46 |
| 1977-78 | 0.27 | 0.64 | 2006-07 | 0.38 | 0.46 |
| 1978-79 | 0.28 | 0.62 | 2007-08 | 0.38 | 0.45 |
| 1979-80 | 0.30 | 0.59 | 2008-09 | 0.39 | 0.44 |
| 1980-81 | 0.29 | 0.60 | 2009-10 | 0.39 | 0.44 |
| 1981-82 | 0.30 | 0.60 | 2010-11 | 0.39 | 0.44 |
| 1982-83 | 0.33 | 0.56 | 2011-12 | 0.40 | 0.43 |
| 1983-84 | 0.35 | 0.54 | 2012-13 | 0.39 | 0.44 |
| 1984-85 | 0.33 | 0.55 | 2013-14 | 0.40 | 0.44 |
| 1985-86 | 0.33 | 0.55 | 2014-15 | 0.41 | 0.43 |
| 1986-87 | 0.34 | 0.53 | 2015-16 | 0.41 | 0.43 |
| 1987-88 | 0.33 | 0.54 | 2016-17 | 0.41 | 0.42 |
| 1988-89 | 0.33 | 0.53 | 2017-18 | 0.41 | 0.42 |

*Sources:* Directorate of Economics and Statistics

Note: HHI represents Herfindhal Index; CEI represents the Composite Entropy Index

It found that the value of CEI index has declined from 0.59 in 1960-61 to 0.42 in 2017-18, whereas HHI has increased from 0.30 to 0.41. It found that the CEI and HHI index both furnished the same results, enhancing the claim that farmers started focusing only on specialization. The results are consistent with the findings of Singh and Sidhu (2004) in which they argued that the specialization has taken place in wheat-paddy due to better return from wheat-paddy rotation, which was considered as the outcome of increase in irrigation facilitices at subsidized rates and market support for these crops.

### *3.4.4 Inter-temporal movement analysis of crops*

Table 3.4 presents both the multi-annual and binary measures for the inter-temporal mobility of the crops in terms of area under cultivation, production, and productivity. The both $RC_{at}$ and $RC_t$ illustrate that there exists a downward trend as shown in Table 3.4 during the entire period. However, most interesting point is that values have come down from 1 to 0.71 for area, 1 to 0.70 for production, and 1 to 0.91 for productivity. This observation supports the findings that mobility of the crops within the overall distribution is virtually lower.

It reflects the fact that farmers have consistently devoted specific area to a few selected crops. This is mainly the result of the emergence of MSP backed agricultural policy.

**Table 3.4:** Inter-temporal movement of $RC_t$ and RCat of area, production, and productivity of crops

| Year | Area | | Production | | Productivity | | Year | Area | | Production | | Productivity | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RCat | RCt | RCat | RCt | RCat | RCt | | RCat | RCt | RCat | RCt | RCat | RCt |
| 1960-61 | 1 | 1 | 1 | 1 | 1 | 1 | 1989-90 | 0.927 | 0.920 | 0.868 | 0.845 | 0.968 | 0.957 |
| 1961-62 | 0.990 | 0.990 | 0.977 | 0.977 | 0.995 | 0.995 | 1990-91 | 0.927 | 0.920 | 0.841 | 0.843 | 0.964 | 0.957 |
| 1962-63 | 0.990 | 0.990 | 0.977 | 0.968 | 0.991 | 0.986 | 1991-92 | 0.877 | 0.918 | 0.759 | 0.838 | 0.968 | 0.957 |
| 1963-64 | 0.993 | 0.990 | 0.973 | 0.968 | 0.986 | 0.982 | 1992-93 | 0.877 | 0.916 | 0.818 | 0.838 | 0.968 | 0.957 |
| 1964-65 | 0.991 | 0.993 | 0.982 | 0.969 | 0.973 | 0.971 | 1993-94 | 0.905 | 0.916 | 0.818 | 0.838 | 0.973 | 0.958 |
| 1965-66 | 0.980 | 0.992 | 0.968 | 0.961 | 0.986 | 0.973 | 1994-95 | 0.905 | 0.916 | 0.800 | 0.836 | 0.968 | 0.958 |
| 1966-67 | 0.982 | 0.987 | 0.968 | 0.959 | 0.986 | 0.973 | 1995-96 | 0.868 | 0.914 | 0.814 | 0.836 | 0.968 | 0.958 |
| 1967-68 | 0.959 | 0.976 | 0.945 | 0.951 | 0.968 | 0.965 | 1996-97 | 0.850 | 0.909 | 0.795 | 0.835 | 0.959 | 0.958 |
| 1968-69 | 0.964 | 0.969 | 0.891 | 0.934 | 0.964 | 0.960 | 1997-98 | 0.864 | 0.907 | 0.773 | 0.834 | 0.959 | 0.958 |
| 1969-70 | 0.973 | 0.968 | 0.909 | 0.926 | 0.964 | 0.953 | 1998-99 | 0.823 | 0.903 | 0.782 | 0.833 | 0.964 | 0.958 |
| 1970-71 | 0.964 | 0.966 | 0.909 | 0.921 | 0.959 | 0.951 | 1999-00 | 0.827 | 0.900 | 0.777 | 0.833 | 0.964 | 0.958 |
| 1971-72 | 0.945 | 0.960 | 0.932 | 0.919 | 0.964 | 0.950 | 2000-01 | 0.868 | 0.899 | 0.764 | 0.832 | 0.968 | 0.958 |
| 1972-73 | 0.945 | 0.957 | 0.932 | 0.918 | 0.977 | 0.951 | 2001-02 | 0.827 | 0.896 | 0.777 | 0.833 | 0.927 | 0.954 |
| 1973-74 | 0.920 | 0.951 | 0.936 | 0.917 | 0.955 | 0.949 | 2002-03 | 0.814 | 0.892 | 0.777 | 0.833 | 0.968 | 0.954 |
| 1974-75 | 0.909 | 0.941 | 0.873 | 0.905 | 0.977 | 0.952 | 2003-04 | 0.827 | 0.890 | 0.777 | 0.834 | 0.968 | 0.955 |
| 1975-76 | 0.927 | 0.939 | 0.914 | 0.903 | 0.973 | 0.952 | 2004-05 | 0.832 | 0.889 | 0.777 | 0.834 | 0.968 | 0.955 |
| 1976-77 | 0.936 | 0.936 | 0.909 | 0.901 | 0.964 | 0.950 | 2005-06 | 0.814 | 0.887 | 0.691 | 0.830 | 0.968 | 0.956 |
| 1977-78 | 0.936 | 0.932 | 0.886 | 0.892 | 0.973 | 0.951 | 2006-07 | 0.795 | 0.884 | 0.709 | 0.828 | 0.968 | 0.956 |
| 1978-79 | 0.936 | 0.930 | 0.886 | 0.886 | 0.968 | 0.952 | 2007-08 | 0.795 | 0.881 | 0.709 | 0.826 | 0.968 | 0.957 |
| 1979-80 | 0.936 | 0.928 | 0.850 | 0.877 | 0.977 | 0.954 | 2008-09 | 0.782 | 0.877 | 0.705 | 0.824 | 0.973 | 0.957 |
| 1980-81 | 0.925 | 0.927 | 0.850 | 0.870 | 0.959 | 0.954 | 2009-10 | 0.786 | 0.874 | 0.705 | 0.823 | 0.982 | 0.958 |
| 1981-82 | 0.936 | 0.926 | 0.768 | 0.857 | 0.959 | 0.954 | 2010-11 | 0.795 | 0.872 | 0.705 | 0.821 | 0.982 | 0.959 |
| 1982-83 | 0.936 | 0.925 | 0.836 | 0.853 | 0.968 | 0.955 | 2011-12 | 0.782 | 0.870 | 0.705 | 0.820 | 0.982 | 0.958 |
| 1983-84 | 0.936 | 0.925 | 0.877 | 0.854 | 0.968 | 0.956 | 2012-13 | 0.805 | 0.868 | 0.750 | 0.820 | 0.914 | 0.955 |
| 1984-85 | 0.941 | 0.924 | 0.823 | 0.851 | 0.973 | 0.957 | 2013-14 | 0.795 | 0.867 | 0.709 | 0.820 | 0.914 | 0.951 |
| 1985-86 | 0.927 | 0.922 | 0.859 | 0.849 | 0.977 | 0.956 | 2014-15 | 0.818 | 0.865 | 0.695 | 0.818 | 0.911 | 0.947 |
| 1986-87 | 0.927 | 0.920 | 0.868 | 0.849 | 0.959 | 0.956 | 2015-16 | 0.777 | 0.862 | 0.695 | 0.817 | 0.911 | 0.943 |
| 1987-88 | 0.905 | 0.920 | 0.832 | 0.847 | 0.968 | 0.957 | 2016-17 | 0.745 | 0.859 | 0.695 | 0.816 | 0.911 | 0.939 |
| 1988-89 | 0.927 | 0.920 | 0.827 | 0.843 | 0.968 | 0.957 | 2017-18 | 0.714 | 0.854 | 0.709 | 0.816 | 0.911 | 0.936 |

*3.4.5 Decomposition of sources of growth in agricultural output*

Above analysis of area, production, and productivity of the selected crops in Punjab merely explains the growth pattern and its direction of change. This cannot give a confirmation of the effect of area and productivity on the total variation in the production of the crops. To know about this, decomposition analysis is applied here. Table 3.5 illustrates crop-wise area effect, yield effect, and interaction effect to total output change. In the case of wheat; area, yield, and interaction effects have contributed about 37.50 percent, 32.57 percent, and 29.93 percent respectively during the period 1960-61 to 1989-90. It is observed that the area and yield effects have increased continuously from 44.19 percent to 50.16 percent respectively, whereas the interaction effect has contributed only 5 percent during 1990-91 to 2017-18. The decline in interaction effect is captured by area and yield components.

Similarly, in case of paddy; area, yield, and interaction effects have contributed about 8.21 percent, 37 percent and 67.17 percent respectively from 1960-61 to 1989-90. The contributions of area and yield effects have increased to 41.92 percent and 67.17 percent, while the contribution of interaction effect has declined to about -9.08 percent during 1990-91 to 2017-18. Except wheat and paddy, other crops have shown declining trends in terms of their contributions of area effect, yield effect, and interaction effect. In terms of production, potato is an important vegetable crop produced in Punjab but the analysis shows the deceleration of area effect and yield effect under cultivation of this crop. It can be observed that the decline in diversification system is influenced by increasing contribution of area effect and yield effect of land to the production of crops, especially for the wheat and paddy.

As stated in the literature, increasing agricultural output is possible either through expanding the area under crops or enhancing the productivity of the crops or through both. Area under a crops can be increased by substituting one with another and productivity can be enhanced through the adoption of various yield enhancing technologies. However, the present outcomes show that, in case of pulses, neither the area under the crops nor the productivity has increased during the last four decades; whereas increase in cereal production was caused by an increase in both area and yield.

**Table 3.5:** Area, yield and interaction effect of the crops

| Crops | 1960-61 to 1989-90 | | | 1975-76 to 2004-05 | | | 1990-91 to 2017-18 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Area Effect | Yield Effect | Interaction Effect | Area Effect | Yield Effect | Interaction Effect | Area Effect | Yield Effect | Interaction Effect |
| Wheat | 37.50 | 32.57 | 29.93 | 49.00 | 47.67 | 03.33 | 44.19 | 50.16 | 05.65 |
| Paddy | 08.21 | 37.30 | 54.49 | 15.84 | 71.31 | 12.85 | 41.92 | 67.17 | -9.08 |
| Cotton | 57.39 | 34.54 | 08.07 | 73.58 | 45.88 | -19.46 | 45.46 | 41.82 | 12.72 |
| Maize | 19.73 | 68.48 | 11.79 | 28.71 | 72.88 | -1.59 | 05.81 | 54.90 | 39.29 |
| TOS | 20.63 | 72.95 | 06.42 | 29.63 | 78.10 | -7.73 | 11.42 | 70.20 | -12.69 |
| Potatoes | 0.04 | 83.87 | 16.09 | 00.34 | 99.38 | 0.29 | 0.19 | 81.60 | -44.83 |
| SUG | 70.12 | 18.88 | 10.99 | 83.72 | 39.42 | -23.13 | 60.37 | 35.51 | 04.11 |
| TP | 77.07 | 23.31 | -0.38 | 33.55 | 70.25 | -3.80 | 13.17 | 64.87 | 21.97 |
| Barley | 03.75 | 47.56 | 48.68 | 8.80 | 92.72 | -1.51 | 01.18 | 88.87 | 09.95 |
| Onion | 0.0006 | 75.78 | 24.22 | 00.03 | 99.92 | 00.05 | 00.01 | 93.35 | 06.65 |
| Bajra | 14.69 | 56.88 | 28.43 | 14.88 | 85.55 | -0.43 | 00.98 | 97.48 | 01.54 |

Sources: Directorate of Economics and Statistics (DES)
Note: TOS=Total Oil Seeds, SUG= Sugarcane, TP = Total Pulses

It is pointed out that, continuous decline in productivity under pulses is caused by the low yield during 1960-61 to 2017-18. The farmers give less emphasis on the pulses crops because of the low availability of inputs, higher risk in production, non- availability of quality seed, low market demand, high labour needs, lack of production techniques of pulses at farm level and absence of proper care (Bhatia, 1991; Singh & Grover, 2015).

Table 3.6 presents the overall picture of each component along with its interaction effects. On the individual level, it shows that during 1960-61 to 1974-75 around 41 percent and 30 percent growth is accounted by yield and area effects respectively, whereas cropping pattern effect have contributed only a meager proportion of 0.49 percent. But this pattern has changed during 2005-06 to 2017-18, where area effect has gone down to 5.56 percent while yield and cropping pattern effects have increased to 94.97 percent and 69.22 percent respectively. Moreover, the interaction effect of area, yield and cropping pattern contribute only 3.71 percent to the total agricultural production, while the highest proportion of 12.42 percent is contributed by the combined effects of yield and cropping pattern. In brief, the results clearly indicate that major part in total production is accounted by growth in yield followed by cropping pattern.

**Table 3.6:** Sources of agricultural growth in Punjab

| Effects | 1960-61 to 1974-75 | 1975-76 to 1989-90 | 1990-91 to 2004-05 | 2005-06 to 2017-18 |
|---|---|---|---|---|
| Individual | | | | |
| Area Effect | 29.73 | 15.76 | 4.41 | 5.56 |
| Yield effect | 41.18 | 40.01 | 53.57 | 94.97 |
| Cropping effect | 0.49 | 21.43 | 24.15 | 69.22 |
| Sub total | 71.40 | 77.20 | 82.13 | 169.75 |
| Interaction | | | | |
| Area and Cropping pattern | 0.15 | 3.90 | 1.38 | 0.25 |
| Area and Yield | 12.31 | 7.28 | 3.07 | 0.34 |
| Cropping and Yield | 12.42 | 9.83 | 12.69 | -70.09 |
| Area, yield and cropping pattern | 3.71 | 1.79 | 0.73 | -0.25 |
| Sub total | 28.60 | 22.80 | 17.87 | -69.75 |
| Grand total | 100 | 100 | 100 | 100 |

*Source:* Author's Calculation by using data from Directorate of Economics and Statistics

*3.4.6 Determinants of crop diversification*

Table 3.7 presents the factors that affect the level of crop diversification. The results found that the variables number of market per hectare, length of road per hectare, urbanization, number of tractor per hectare, and rainfall per hectare have a statistically significant and positive impact on diversification as expected, whereas the amount of fertilizer per hectare, intensity of irrigation per hectare, and cropping intensity have a negative impact on crop diversification. Since the coefficient of two variables LMARKT (00471) and LROAD (00228) are positive and statistical significant, it suggested that infrastructure aspects in Punjab have positive impact on crop diversification. But, over-dependence of the farmers on irrigation and fertilizer is negatively impacting degree of crop diversification. As the results shows the coefficient of two variables LNPK (-0.0622) and LIRRINTY (-0.0623) are negatively and statistically significant.

**Table 3.7:** Estimated regression coefficients of Equation (3.8)

| Variables | (1) | (2) |
|---|---|---|
| | Composite Entropy Index | |
| | Pooled OLS | Fixed Effects |
| LMARKT | 0.0199*** | 0.0471*** |
| | (0.0072) | (0.0105) |
| LROAD | 0.0237*** | 0.0228*** |
| | (0.0039) | (0.0033) |
| LNPK | -0.0690*** | -0.0622*** |
| | (0.0063) | (0.0088) |
| LIRRINTY | -0.0947*** | -0.0623** |
| | (0.0248) | (0.0259) |
| LUB | 0.0337** | 0.0341*** |
| | (0.0139) | (0.0090) |
| LTRC | 0.0020*** | 0.0024*** |
| | (0.0007) | (0.0004) |
| LRAIN | 0.0197*** | -0.0749 |
| | (0.0044) | (0.0456) |
| LCI | -0.0912** | 1.1866*** |
| | (0.0451) | (0.1738) |
| Constant | 1.1179*** | |
| | (0.1544) | 438 |
| | | 49 |
| Observations | 435 | 0.3902 |
| Number of year | 0.7118 | 0.380 |
| R-squared | 0.706 | 0.4398 |
| Adjusted R-Squared | 117.6 | 0.428 |
| F stat | -0.0199*** | 64.46 |

Note: Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

## 3.5 Conclusion and Policy Implications

The objectives of this chapter were (i) to explore the trend and pattern of crop diversification in Punjab, and (ii) identify the factors those determine crop diversification. HHI and CEI have been estimated to measure the degree of crop diversification for 1960-61 to 2017-18. The findings reveal that cropping pattern has changed in Punjab state. The green revolution shifted focus of farmers towards a few crops mainly wheat-rice rotation. These crops have sowed on maximum area due to favourable conditions such as relatively higher and stable returns, low uncertainties in production and remunerative ensured price as compared to other competing crops. Even though if it look throughout the study period, state has achieved acceleration in growth in productivity of maize, cotton and total pulses but the state is still concentrated on wheat-rice pattern. This remarkable change in cropping pattern is the result of wider usage of high yielding variety seeds, electricity policy, and food procurement policy introduced during the green revolution period. More specifically, regarding key components responsible for the change in total production are area effect and yield effect. From the above analysis, it can be stated that decline in crop diversification has been influenced by the increasing contribution of the area and yield effects of land to the total production of crops, especially for the wheat and rice crops. Further, it also found the factors number of market per hactare, lengh of road per hactare, urbanization, number of tractor per hactare, and rainfall per hactare are positively related to diversification as expected. But, over-dependence of the farmers on irrigation and fertilizer are negatively impacting degree of crop diversification. As the results shows the coefficient of two variables LNPK (-0.0622) and LIRRINTY (-0.0623) are negatively and statistically significant. The policy perception for the cropping pattern is that the farmers will switch in favour of others crops such as oil seeds, pulses etc. only when they are sure of getting higher profits, less risk and backed by effective procurement policy.

# Chapter-4

# Weather Shocks, Crop Productivity, and Crop Diversification: Adaptation Practices in Punjab

# CHAPTER-4

## ***Weather Shocks, Crop Productivity, and Crop Diversification: Adaptation Practices in Punjab***

# Chapter 4
# Weather Shocks, Crop Productivity, and Crop Diversification: Adaptation Practices in Punjab

## 4.1 Introduction

In recent years, assessing the nature and relationship of climate shocks with agricultural yield become a great interest for policy-makers and researchers. It is because of the agriculture sector most sensitive to the effect of climate changeability (McCord et al., 2015; Thulstrup, 2015; Tol, 2018). Such an interest is more eminent in those areas where agriculture output is often determined by the whims of nature and crop growers have a lack of adaptive capacity or well information to cope with such extreme shocks (Mendelsohn et al., 2006; Nelson et al., 2009).

A number of studies on weather shocks support the fact that frequent occurrence of weather shocks drastically damaged crop productivity and food supply (IPCC, 2012; Dercon & Christiaensen, 2011). The developing economies like India are more vulnerable to climate shocks due to their deficiency in capital availability, adequate technologies, infrastructure, and organizations to cope with such shocks. In India, studies have reported that climate shocks reduce agricultural productivity by 25 percent (Birthal et al., 2014) and increase poverty by 12-33 percent (Bhandari et al., 2007). Birthal et al. (2015) have further observed that in India 1/3$^{rd}$ of the rice area has been affected by droughts. Similarly, in the context of eastern India, it was noticed that a household income declined by 25-60 percent during a drought year (Pandey et al., 2007). Further, it has been found that the rainfall shocks have reduced agricultural productivity by 42 percent in case of Nigeria (Amare et al., 2018).

However, in the literature, unfavorable effects of high temperature and rainfall on agricultural yield have been widely discussed (Baker et al., 1992; Kumar & Parikh, 2001; Kimball et al., 2002; Jalota et al., 2009; Kaur et al., 2012; Alauddin & Sarkar, 2014; Burke & Emerick, 2016; Chuang, 2019; Shahzad & Abdulai, 2020), and stated that higher variation in temperature or rainfall has threatened livelihoods of agricultural based population. Further, it has been reported that the frequency of occurrence of climate events in state has risen in the recent past and is predicted to rise in the future (Mahajan et al., 2009; World Bank, 2013; Jalota et al., 2014).

In addition, there are a few studies existing in earlier literature that have partly discussed the impacts of timing of monsoon arrival on crop productivity (Binswanger & Rosenzweig, 1993; Sultan et al., 2005; Naylor et al., 2007; Talathi et al., 2008; Gine et al., 2008; Marteau et al., 2011; Jain et al., 2015; Kala, 2017; Detroja et al., 2018; Singh et al., 2020) and they have observed that variation in arrival of timing of monsoon might affect crop productivity. The evidence found from South and Southeast Asia revealed that delayed monsoon arrival from its normal date has adversely affected the crop productivity (Laux et al., 2008). In context of Semi-arid regions in India, it was found that delayed monsoon arrival reduces profits of the cultivators by 15 percent, but the impact being greater on poor farmers (Binswanger & Rosenzweig, 1993). In particular, it is observed that the performance of agriculture is influenced not only by the quantum of rainfall but also by its timing.

In most of the rain-fed areas, farmers depend upon monsoon to begin various agricultural activities. However, untimely rainfall patterns may have serious implications on the overall economy of an agricultural household (Singh et al., 2020). However, it is considered that negative impact of weather shocks on crop productivity could be reduced by applying some risk-coping mechanisms such as infrastructure improvements, management programs, and agricultural insurance in current agriculture systems (Smit & Skinner, 2002; Howden et al., 2007). Besides, other adaptations include viz., diversification into alternative varieties of specific crops (i.e., drought-resistant, early maturing), altering fertilization amount or timing of irrigation, implementing shading, and conservation agriculture such as soil protection, agroforestry (Easterling et al., 2007; Dasgupta et al., 2014; Porter et al., 2014). Some of the studies reported that irrigation has played a significant role in mitigating the effects of extreme climate (Birthal et al., 2014), and also revealed that irrigation may be an endogenous choice sensitive to climate events (Kurukulasuriya et al., 2011). Besides irrigation, crop diversification has widely discussed as an adaptation application to reduce the effects of climatic shocks (Di Falco & Chavas, 2009; Macours et al., 2012; Mitter et al., 2015; Thamo et al., 2017; Asfaw et al., 2018) and also a supporter of sustainable agrarian system (Joshi et al., 2004; Nguyen, 2017). Crop diversification is well documented technology and it seems to be one of the climate smart practices that helps in reducing climate risk, improves food security, and enhances productivity, and helps in mitigation of GHG emissions (FAO, 2013; Rosenstock et al., 2016; Lipper et al., 2017). In the North China plain, it is observed that the suitable diversified cropping systems have a lower carbon footprint (Yang et al., 2014). Accordingly, Birthal and Hazrana (2019) suggested that crop diversification is an important ex-ante adaptation measure to climatic shocks; and its adaptation benefits are more apparent against severe shocks and in the long-run. Therefore, by using various potential risk-coping appliances, farmers can recover the loss of assets in such economies. As in India majority of the farmers have small land holdings and they are economically weak and unable to invest in costlier adaptations; crop diversification is one of the low-cost effective adaptations to avoid productivity loss due to delayed monsoon arrival for these farmers.

The study of Singh et al. (2020) is an exclusive attempt that has seen the impact of delayed onset rainy day on crop productivity in different districts in India at an aggregate level.

However, they ignored the impact of delayed monsoon arrival on regional level and have considered the role played by irrigation in mitigating the adverse effect from climate shocks. The present study adds to this strand of literature by estimating the role of crop diversification as an adaptation practices to minimize these weather effects. Therefore, present study revisits the debate on relationship between weather shocks and crop yield particular in Punjab, and farmers' adaptation measures to cope-up with such losses in productivity due to changes in timing of monsoon arrival. Punjab is agriculturally advanced state and has three times larger land holding size than the national average of 1.15 hectare (Singh et al., 2017). The agricultural development in the Punjab state is clearly visible from the facts that it has the largest proportion of irrigated area (98 percent), highest cropping intensity (about 190 percent) and the most intensive use of chemical fertilizers (246 kg/ha) and other inputs. Rainfall is confined three to four months in a year, and it varies from about 250 mm in South-west parts of the state to about 1000 mm in the northern region of state (Government of Punjab, 2008). By using district level panel dataset (1966-2015) collected from ICRISAT and IMD in Punjab, this study has focused on mainly two issues: - (i) to assess the impact of weather shocks on crop productivity; and (ii) to examine the adaptation benefits of crop diversification against weather shocks.

This chapter contributes to the literature in following way: - First, it examines the impacts of weather shocks on agricultural productivity. Although a significant body of literature has widely studied and intensively debated on the impact of climate change on crop production particular in Punjab as a whole (Hundal, 2007; Kaur et al., 2008; Jalota et al., 2009; Vashisht et al., 2013; Jalota et al., 2014) but impact of timing of monsoon arrival on crop productivity in particular state is rare. There are no rigorous attempts of addressing the issue at micro unit level such as in particular state across districts. The impact of weather change is region-specific issue, therefore, there is a need to strengthen region-specific early warning systems to provide farmers timely information on weather conditions. This chapter accomplishes this gap in the existing literature. It is important to see the extent of timing of monsoon arrival and its regional distribution at micro unit. This would lead to identify the micro level problems of farm sector followed by appropriate policy formation. Second, it examines adaptation effect of other inputs such as fertilizers, and irrigations to cope-up against this weather shocks. This aspect is not explored in the existing studies. In this context, this chapter particular focuses on the role played by crop diversification or other adaptation practices in farming systems to cope-up with weather shock (delayed monsoon).

The remaining part of chapter is organized as: - Section 4.2 describes sources of data, descriptive statistics of the variables, constructed diversification index and extreme monsoon onset day index. Section 4.3 presents the empirical framework of the study. Section 4.4 presents the model results. Finally, the conclusions and policy implications are summarized in Section 4.5.

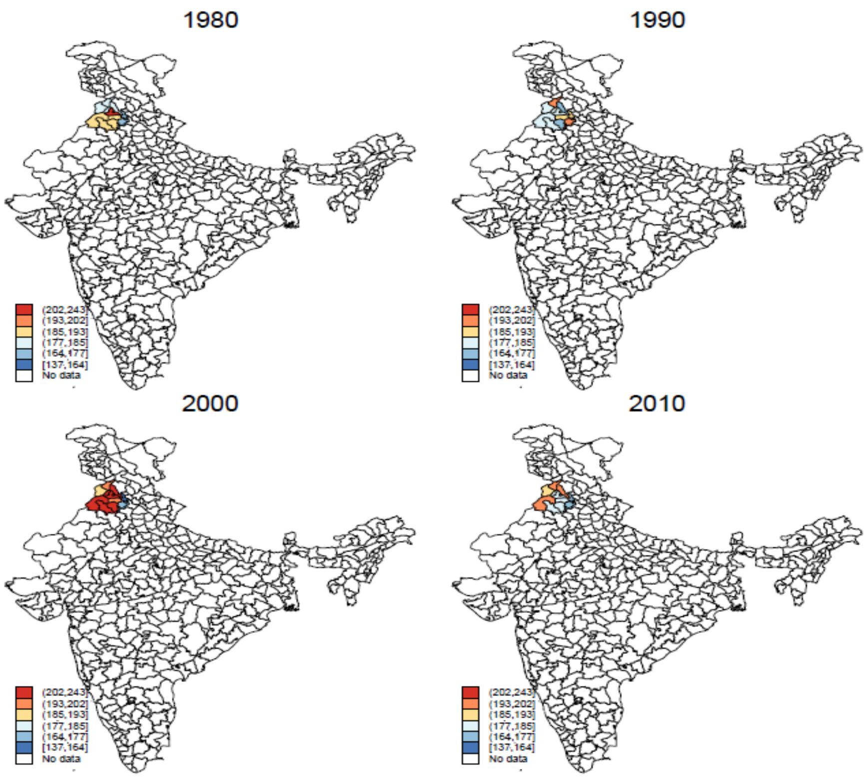
## 4.2 Data Sources and Descriptive Statistics

### *4.2.1 Data sources*

The present study mainly used two sources of dataset viz., crop production data and weather data. The crop production data on area, yield, and inputs (i.e., fertilizer and share of cropped irrigated area) has been collected primarily from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). This dataset consist of district-level information for 20 states of India with different agriculture and socio-economic characteristics from 1966-2015. However, this study is only concentrated on Punjab state. Detailed information on output and inputs variables viz., crops grown area covered under each crop; inputs like fertilizer, irrigation, and farm harvest prices (FHP) has been collected on major eleven crops (i.e., rice, wheat, sorghum, pearlmillet, maize, fingermillet, pigeonpea, groundnut, chickpea, rapeseed, cotton) for Punjab, which together accounted for 92 percent area of production. The data has been divided into the apportioned and unapportioned database; but this study considered only the apportioned dataset (i.e. data for 1966 district boundaries). However, for analysis the final record of panel data has been set for major 11 districts in Punjab. Secondly, the data on weather variable i.e. rainfall across districts has been extracted from high-resolution ($0.25^0$ x $0.25^0$) daily gridded dataset available from the IMD (India Metrological Department) for the period 1966-2015. In this study, daily rainfall data has been used, and converted into district level. For this purpose, the study has used the district level geographic coordinates to specify the nearest grid point to each district to get information about the monsoon arrival.

Before moving ahead, it tries to observe the distribution of rainfall across districts. The results find that monsoon varies across different districts in the state as shown in Figure (4.1). For the particular case of Punjab, maps are shown in Figure B1 in Appendix B.

**Figure 4.1:** Variation in monsoon onset day across districts in Punjab




Note: This figure presents the changes in the spatial and temporal pattern of monsoon arrival over 1980-2010 across the districts.

*4.2.2 Onset of the rainy season and precipitation index*

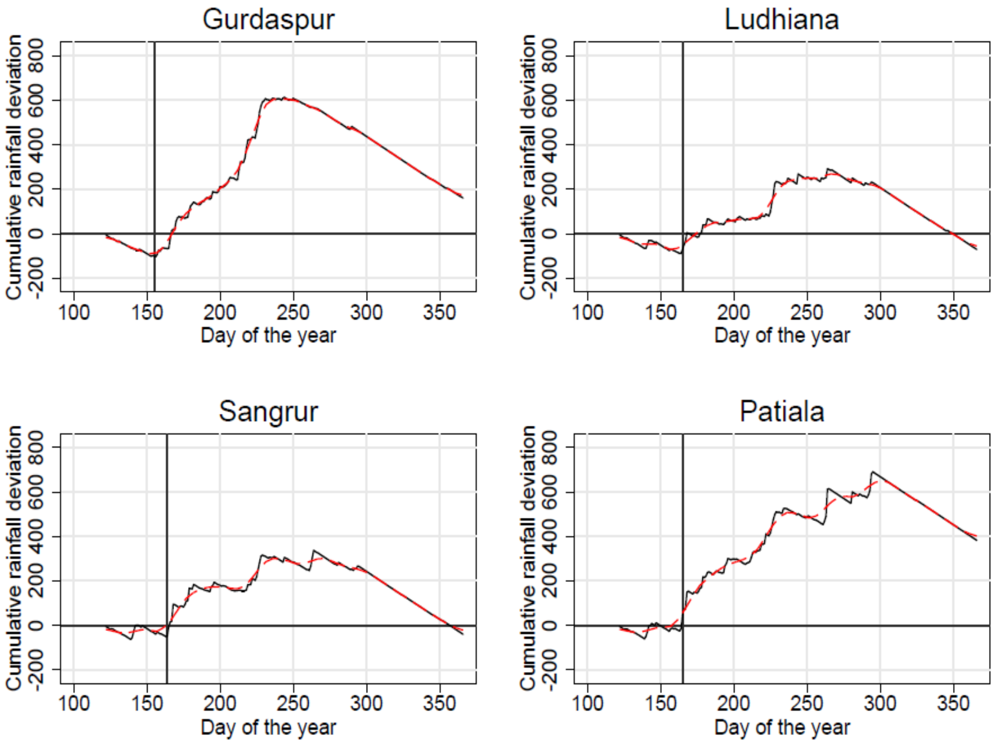
To measure the structure of onset of rainfall, various indices have been carried out by different studies (Liebmann & Marengo, 2001; Chen et al., 2004; Bombardi & Carvalho, 2009). Thus, in this analysis, methodology used by Boombardi et al. (2017) has been followed to construct the onset of monsoon in different years across districts. This index also captured the combined effect of duration and intensity of rainfall. For this methodology, daily rainfall accumulated anomalies has used at each grid point for each year as the sum of daily rainfall anomalies from *1st May* to the specified day as follows:

$$S(d) = \sum_{t=May,1^{st}}^{d} (P(n) - Pc)$$

*(4.1)*

In Equation *(4.1)*, $S(d)$ represents the accumulated precipitation deviation from the annual mean at day '$d$', $P\ (n)$ is the daily rainfall at day '$n$', $Pc$ is average of daily rainfall in a particular year. Here, *t* is the starting date of the monsoon. Here, *1st* May or *122nd* day of the calendar year is selected as the arrival day of monsoon. According to India Meteorological Department (IMD), the monsoon does not start before *10th* May. Thus, a date in early May would be appropriate for measuring the onset of rainy day to avoid occurrence of maximum false rainy onsets. In Equation *(4.1)*, the rainy days in the months of the May, June, July, and August (MJJA) are considered, because maximum rain has been recorded in these months (IMD).

**Figure 4.2:** Arrival of monsoon onset across different districts in Punjab




Note: This figure presents the arrival of monsoon onset across different districts in Punjab.

Figure 4.2 represents the construction of onset rainy day. In this estimation, the onset rainy day is considered as the first inflection point at which the $S(d)$ curve touches its minimum but start turning upward thereafter. In Figure (4.2), vertical blackline display the accumulated rainfall deviation $S(d)$ from the mean. It is observed that the onset rainy day varies across the districts. In case of Gurdaspur, monsoon arrives on 167 day as shown by the vertical line in the Figure (4.2), however in Ludhiana it arrives on the 171 day. By this process, monsoon arrival day in different districts of Punjab can be found.

Table 4.1 represents the summary statistics for the monsoon onset day, various districts show that the onset rainy day varies across districts with an average of 192$^{th}$ days of the calendar years. However, for analysis purposes, we have considered only those days where the onset of rainy day arises with extreme delays, which varies with the mean value of 223 day in Punjab.

**Table 4.1:** Summary statistics of the monsoon onset day

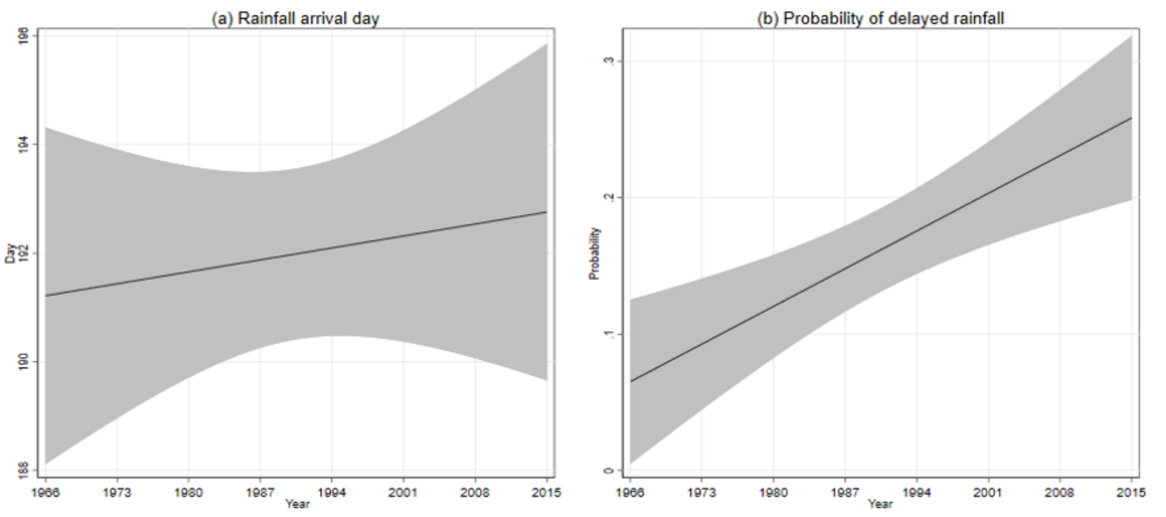
| Standardized values | Min | Mean | Max | SD |
|---|---|---|---|---|
| 0 | 139 | 185 | 218 | 13 |
| 1 | 205 | 223 | 243 | 9 |
| Total | 139 | 192 | 243 | 18 |

Note: this table presents the summary statistics of arrival of monsoon day across different districts in Punjab.

*4.2.3 Evidence on climate change*

There has been a substantial change in the onset of rainy season across different districts over 1966-2015. In examining the trend and the probability of the onset of rainy day in India, it was found that over time onset of rainy day has moved forward in the later part of the year (Singh et al., 2020). Figure (4.3) depict that the onset day of monsoon has shifted forward by about a day on average over 1966-2015 as shown in part (a) of Figure (4.3). It can be seen that the probability of delay in monsoon onset has also increased over the considered time period.

**Figure 4.3:** Change in onset of days and probability over 1966-2015 across districts




Note: This figure presents the change in monsoon onset day and probability of monsoon onset day over 1966-2015 across different districts in Punjab.

In part (b) of Figure (4.3), it found that the probability of delay in the onset of monsoon has increased from less than 0.1 in 1966 to 0.27 in 2015. To estimate the day of monsoon arrival over time, regression analysis has been used considering districts fixed effects to control for heterogeneity across different districts; and results are shown in Table 4.2. In the regression analysis, the monsoon onset day and probability of extreme monsoon onset day are regressed on a linear time trend. The outcomes are highlighted in column 1 of Table 4.2 that show a positive but statistically insignificant trend in the arrival of monsoon, which is also displayed in part (a) of Figure (4.3). Overall, the results show that over time the onset of monsoon has shifted forward by about a day on average. Further, it also tests the probability of extreme delay in monsoon, for this purpose, a dummy variable is created. This is defined as 1 if the monsoon arrival day arrives one standard deviation greater than the normal arrival day in a district and 0 otherwise. This dummy variable is regressed on a linear time trend and district fixed effects. The results are presented in column 2 of Table 4.2., and are also displayed in part (b) of Figure (4.3), which shows that the probability of occurring extreme delay in monsoon arrival has increased over time.

**Table 4.2:** Estimates for change in onset and probability of delayed monsoon across districts

| Variables | (1)<br>Monsoon onset day | (2)<br>Extreme monsoon onset day |
|---|---|---|
| Year | 0.033 | 0.004*** |
| | (0.060) | (0.001) |
| Observations | 550 | 550 |
| R-squared | 0.001 | 0.024 |
| District FE | Yes | Yes |
| Adjusted R-squared | -0.0012 | 0.0222 |
| F stat | 0.294 | 13.40 |
| Mean of dependent variable | 192 | 0.162 |

Note: This table represents regression results for change in onset and probability of delayed monsoon occurrence during 1966-2015. In column 1, the district level rainfall arrival days are regressed on a linear time trend while controlling for the district fixed effects. In column 2, the dependent variable is a dummy variable which is coded as 1 if the rainfall arrival day is greater than the mean arrival day in a district and zero otherwise. This dummy variable is regressed on a linear time trend while controlling for district fixed effects.

*4.2.4 Diversification measures*

Several indices have been used to measures the diversity in cropping system such as Herfindahl Index, Simpson Index, Entropy Index and many more. In spite of their differences, these indices give more or less similar results. In this chapter, Composite Entropy Index (CEI) has been constructed as earlier followed by Shiyani and Pandya (1998).

$$CEI_{it} = -\left(\sum_{i=1}^{N} P * log_N P_i\right) * \{1 - (1/N)\}$$

*(4.2)*

where, $CEI_{it}$ is the diversity in cropping system; $p_i$ is the area share of crop $i$ in the total cropped area. The range of the index lies between 0 & 1; 0 represents complete specialization, whereas 1 represents complete diversification. Since index uses $-log_N P_i$ as weights, it assign more to lower quantity and less weight to higher quantity. For more clarification see Figure B2 and Figure B3 for different district in Appendix B.

**4.3 Empirical Frameworks**

There are mainly three approaches that are widely used to estimate the influence of climate shocks on crop yields i.e., (i) Bio-physical crop modelling approach also known as production function approach (ii) Ricardian approach and (iii) Panel data approach. Each of these approaches has its own advantages and limitations. The majority of the previous studies have used panel data approach proposed by Deschenes and Greenstone (2007). It is because of its numerous advantages over others techniques. For instance, by using panel data approach, it is possible to capture the effects of time-invariant variables such as geographical characteristics (i.e., soils and water quality). Moreover, it considers farmers' responses or adaptations to changes in weather change. Further, it is possible to account the short-term effects of adaptations on yield, as in response to yearly variations in weather variables the crop growers can adjust their crop mix, input usages etc. One more benefit to use this approach is that the geographical fixed effect absorbs location-specific time variant determinants of crop yield that may be correlated with climate variables (Deschenes & Greenstone, 2007). Therefore, in this chapter, to examine the impacts of extreme delay in monsoon arrival on agricultural productivity, panel data approach is used.

*4.3.1 Extreme monsoon onset day and crop productivity*

To estimates the impact of delayed monsoon onset on agricultural productivity, it follows this specification:

$$Y_{it} = a_i + \sigma x_{it} + \sum_{i=1}^{N} \rho_i (a_i \times T) + \beta_1 d\_day_{it} + \varepsilon_{it}$$

*(4.3)*

where, $Y_{it}$is the log of agricultural productivity in district *i* in year *t*. $a_i$ represents the district fixed effect that absorb time-invariant unobserved factors (i.e., geographical characteristics of districts); thus with this fixed effects the predictable coefficients of $\beta$*'s* are likely to be unbiased and consistent. $x_{it}$ represents the vector of others additional inputs as controls (i.e., fertilizer and share of crop irrigated area). Further, $(a_i \times T)$ is a district-specific exponential time trend to switch for the district-specific heterogeneity in yield growth due to other technological change; $\rho_i$ is coefficient of time trend across districts. $d\_day_{it}$ is a categorical variable for delayed monsoon arrival in district *i* in year *t* named as 'extreme monsoon onset day'; *d_day* is a categorical value where it takes the value 1 if a district *i* in time period *t* receives one standard deviation greater than normal arrival day delay in monsoon arrival and 0 otherwise. $\varepsilon_{it}$ is a residual noise term that comprises the effects of other random factors. In

Equation (4.3), $\beta_1$is our main interest parameter that estimates the variation in agricultural productivity due to a one standard deviation delay in the onset of monsoon.

### *4.3.2 Monsoon onset day, crop productivity, and crop diversification*

In Equation (4.3) agricultural productivity is a linear function of the timing of monsoon. However, to test whether crop diversification is an effective adaptation measure to cope with effects of delayed monsoon on agricultural productivity, the modify Equation (4.3) to include an interaction term of extreme delay in monsoon onset day $(d\_day_{it})$ with diversification index (CEI) and specify it as:

$$Y_{it} = a_i + \sigma x_{it} + \sum_{i=1}^{N} \rho_i (a_i \times T) + \beta_1 d\_day_{it} + \beta_2 CEI_{it} + \beta_3 (CEI_{it} \times d\_day_{it}) + \varepsilon_{it} \tag{4.4}$$

In Equation (4.4), $(\beta_1 d\_day_{it} + \beta_2 CEI_{it} + \beta_3 (CEI_{it} \times d\_day_{it}))$ represents the variation in agricultural productivity due to delayed monsoon and crop diversification; $x_{it}$ is a vector of others additional inputs as controls (i.e., amount of fertilizer and share of crop irrigated area); and $\varepsilon_{it}$ is a residual noise term that comprises the effects of other random factors.

## 4.4 Empirical Results

The results begin with the estimation of Equation (4.3) by using panel dataset regression model after controlling for district and time fixed effects. Equation (4.3) gives us only the impact of delayed monsoon arrival on agricultural productivity. In another, Equation (4.4), it estimates the role of crop diversification as dominant adaptation strategy to cope-up with yields loss due to delayed monsoon arrival. However, in order to check the robustness by including additional inputs, the study is estimates two different specifications of Equation (4.4). In one, diversification index is included and allow it to interact with weather variable, to estimate its effectiveness to cope-up with effects of delayed monsoon on agricultural productivity. In another, other additional input variables (i.e., irrigation, fertilizer) are taken control variables.

*4.4.1 Model specification test*

Before proceeding further, to know the impact of delayed monsoon onset on agricultural productivity level, and adaptation strategies or risk coping appliance; it is essential to check the specification of the model. It might be possible that variables that are considered in the model seem to be non-stationary which may lead to spurious estimates. To check for stationarity of variables, the panel unit root test has used (see Table B1 in Appendix B). The test statistics modified inverse $\chi^2$ probability estimation shows that null hypothesis of unit root is rejected. Thus, implying that all the variables are stationary and statistical significant at 1 percent level.

Additionally, the error term might be associated with other explanatory variables generating serial correlation and heteroscedasticity problem within cross section units. It may produce less efficient and biased results. Therefore, to check for the existence of these problems, the study tested following (Arellano & Bond, 1991) for serial correlation. Further, to check for heteroscedasticity, Modified Wald test is applied as shown in Table B2 in Appendix B. The variables that are not important deleted from the model. It found $\chi^2$ statistics to be significant at 1 percent level specifying the presence of heteroscedasticity. Therefore, to control for serial correlation and heteroscedasticity, the standard errors have been clustered at the district level.

To check the appropriate model for the estimation of delayed monsoon impact on agricultural productivity, and suitable adaptation practices, the Housman test is conducted. The results of Housman test favour the fixed effect model over the random effect model. Table B3 in

Appendix B presents the specification of Hausman test to check appropriateness for the chosen fixed effect model with district-specific trend. The test rejected the null hypothesis that contain random effect model is appropriate model, therefore, the results favour the fixed effect regression model.

*4.4.2 Impact of extreme monsoon onset day and crop productivity*

The estimates of Equation (4.3) are presented in Table 4.3. From the estimation, it is found that the coefficients of extreme monsoon onset day is negative and statistically significant for crop-productivity, clearly indicates that a one standard deviation delay in monsoon onset leads to a decline in agricultural productivity. The analysis shows that a one standard deviation delay in monsoon onset lowers agricultural productivity on average of 3.94 percent than the normal arrival day.

**Table 4.3:** Impact of monsoon onset day and crop productivity

| Variables | (1) Crop productivity |
|---|---|
| d_day | -0.0394** |
| | (0.0196) |
| Constant | 8.8882*** |
| | (0.0086) |
| Observations | 542 |
| R-squared | 0.9824 |
| DIST FE | Yes |
| DIST x Time Trend | Yes |
| Adjusted R-Squared | 0.982 |
| F stat | 4.057 |

Note: Dependent variable is log productivity; d_day represents the extreme monsoon onset day. The fixed effects associated with specification are shown in the column. ***, **, and * represents the significance level at 1%, 5%, and 10% respectively. Standard errors are in the parentheses. Standard errors are robust to serial correlation and heteroscedasticity within districts.

It is possible that along with climate variables, other inputs such as share of cropped irrigated area and fertilizers also influence crop productivity. To test for the sensitivity of results to these variables, Equation (4.3) is estimated. Here, irrigation and amount of fertilizer are controlled as presented in Table 4.4. From this estimation, the results are comparable to Table 4.3.

**Table 4.4:** Robustness check with additional control variables of Equation (4.3)

| Variables | (1)<br>Crop productivity |
|---|---|
| d_day | -0.0400** |
| | (0.0164) |
| SIRR | -0.4794** |
| | (0.2361) |
| FERT | 0.0018*** |
| | (0.0002) |
| Constant | 8.9058*** |
| | (0.1188) |
| Observations | 535 |
| R-squared | 0.9863 |
| DIST FE | Yes |
| DIST x Time Trend | Yes |
| Adjusted R-Squared | 0.986 |
| F stat | 21.04 |

Note: presents the estimation of Equation (4.3) with additional variables as a control. Dependent variable is log productivity; d_day represents the extreme monsoon onset day. The fixed effects associated with specification are shown in the column. ***, **, and * represents the significance level at 1%, 5%, and 10% respectively. Standard errors are in the parentheses. Standard errors are robust to serial correlation and heteroscedasticity within districts.

*4.4.3 Impact of delayed monsoon arrival and crop diversification as adaptation measure*

The main concern of this chapter is to evaluate the effect of crop diversification on crop productivity in situation when there is delay in monsoon arrival from its normal date. Table 4.5 presents the estimation of Equation (4.4). The positive and significant coefficient of interaction term of monsoon onset day with crop diversification (CEI) indicates the significant role of crop diversification in reducing losses in productivity that occurred due to adverse effect of delayed monsoon arrival. Additionally, overall the results hold even after controlling at these variables along with crop diversification i.e., share of crop irrigated area, fertilizer. To test for the sensitivity of these variables, the estimates of Equation (4.4) with controls variables (i.e., share of crop irrigated area and amount of fertilizer) are shown in Table 4.6.

**Table 4.5:** Estimated regression coefficient of Equation (4.4)

| Variables | (1) Crop productivity |
|---|---|
| d_day | -0.1984** |
| | (0.0942) |
| CEI | -0.7634*** |
| | (0.1088) |
| d_day × CEI | 0.1725* |
| | (0.0913) |
| Constant | 9.6537*** |
| | (0.1076) |
| Observations | 542 |
| R-squared | 0.9842 |
| DIST FE | Yes |
| DIST x Time Trend | Yes |
| Adjusted R-Squared | 0.983 |
| F stat | 18.41 |

Note: Table 4.5 presents the estimates of Equation (4.4) that includes the interaction of the CEI (Composite Entropy Index) with climate variables (Extreme monsoon onset day). The dependent variable is the log of crop productivity. SIRR represents share of crop irrigated area; FERT is amount of fertilizer. Whereas, *** p<0.01, ** p<0.05, * p<0.1 represent the significance level at 1%, 5%, and 10% respectively. Standard errors are in the parentheses.

**Table 4.6:** Robustness check with additional control variables of Equation (4.4)

| Variables | (1)<br>Crop<br>productivity |
|---|---|
| d_day | -0.1557** |
| | (0.0767) |
| CEI | -0.4435*** |
| | (0.0872) |
| d_day × CEI | 0.1254 |
| | (0.0786) |
| SIRR | -0.5582** |
| | (0.2407) |
| FERT | 0.0015*** |
| | (0.0003) |
| Constant | 9.4240*** |
| | (0.1635) |
| Observations | 535 |
| R-squared | 0.9868 |
| DIST FE | Yes |
| DIST x Time Trend | Yes |
| Adjusted R-Squared | 0.986 |
| F stat | 19.64 |

Note: Table 4.6 presents the estimates of Equation (4.4) with additional inputs. The dependent variable is the log of crop productivity. SIRR represents share of crop irrigated area; FERT is amount of fertilizer. Whereas, "*** p<0.01, ** p<0.05, * p<0.1 represent the significance level at 1%, 5%, and 10% respectively". Standard errors are in the parentheses.

## 4.5 Conclusions

Agricultural production is very sensitive to the effects of weather shocks especially timing of monsoon arrival. Untimely monsoon pattern directly and negatively affect the crop productivity. Considering this adverse impact of untimely monsoon arrival on crop productivity, this chapter explored on the link between monsoon onset day and crop productivity. It also revealed that the farmers can reduce crop productivity losses by adopting some risk-coping strategies. Crop diversification has the potential to offset climate risks and improve agrarian sustainability. Such adaptation practice in agriculture is relevant for developing countries such as India where there is deficiency of financial resources. This analysis evolves in two steps: one, to estimate the impact of weather shocks on crop productivity in Punjab; two, to assess the effectiveness of crop diversification to cope-up with such weather risk.

The empirical investigation suggests that the delayed monsoon arrival has a negative and statistically significant impact on crop productivity. But it also found that crop diversification is playing an important role in reducing the loss of crop productivity that occurred due to adverse impact of delayed monsoon.

Therefore, the findings are clearly indicating the importance of crop diversification as well as other additional inputs in minimizing the losses in agricultural productivity. Since agriculture in the regions where farmers are more diversified, those might be less vulnerable to weather shocks. The findings suggest that farmers, besides the irrigation pattern can also use other possible adaptation measures to cope-up with weather shocks viz., crop diversification, rationalising amount of fertilization.

These findings have important implications for agricultural and development policy; and are likely to offer some useful insights for making climate-resilient agricultural practices in the state.

# Chapter-5

# Economic Efficiency of Agriculture in Punjab

# CHAPTER-5

***Economic Efficiency of Agriculture in Punjab***

5.1 Introduction

5.2 Methodological Frameworks

*5.2.1 Measurement of farm efficiency: CCR and BCC DEA models*

*5.2.2 Super-efficiency model*

*5.2.3 Cost efficiency and allocative efficiency*

*5.2.4 Impact of crop diversification on economic efficiency*

5.3 Data and Specification of Variables

*5.3.1 Descriptive statistics*

5.4 Empirical Results of Crops Cultivation

*5.4.1 Efficiency score and scale operations in crops production*

*5.4.2 Decomposition of OTE: PTE and SE*

*5.4.3 Discrimination of efficient tehsils*

*5.4.4 Discrimination of inefficient tehsils*

5.5 Efficiency Improvement: Slacks and Targets Setting Analysis

5.6 Allocative and Cost Efficiency Analyses

5.7 Impact of Crop Diversification on Economic Efficiency

5.8 Conclusions

# Chapter 5

# Economic Efficiency of Agriculture in Punjab

## 5.1 Introduction

In the developing economics like India, high population growth in the economy and opening of the agriculture sector for export are placing pressure on farmers to produce more. However, the growth in farm production is constraint by accessibility of resources. Therefore, it is considered that production efficiency is a significant factor striving to increase growth of farm production in the economies, where agriculture resources are scarce and opportunities to enhance productivity are dwindling (Ali & Chaudhry, 1990). Such economies can proceeds benefits by improving the efficiency level of neglected resources. They can focus on those areas which have the potential to increase agricultural production without incurring extra costs on inputs and new technology.

A number of studies claim that in less developed economies, the majority of farmers face difficulties in understanding new technologies thereby they failed to reap the benefits of new technologies or make improper allocation of resources (Tadesse & Krishnamoorthy, 1997; Mythili & Shanmugam, 2000; Shanmugam, 2002; Shanmugam & Venkataramani, 2006). For example Kalirajan and Flinn (1983) show that 50 percent inefficiency exists among rice cultivators in Philippines. In the perspective of Pakistan Punjab, Ali and Flinn (1989) show that rice growers can increase their profits by 28 percent through improving farm efficiency. Ali and Chaudhry (1990) follow a similar approach in the same state for different crops and observed that there is an opportunity to enhance farmers' gross income around 13-20 percent without employing any additional resources. Usually, these variations are observed among farmers due to differences in their management abilities, such as farmers who adopt land management and soil conservation practices have relatively higher technical efficiency than their non-adopter counterpart (Solis et al., 2007; Yang et al., 2018; Selejio et al., 2018).

Among India's northern states, Punjab holds a special status in agriculture growth because having healthy mix environmental, institutional and technological factors. The state has a largest contribution to the national pool of food grains such as around 70 percent in wheat and 50 percent in rice production. Currently, wheat and rice become most predominant crops in the state. They covered around 44 percent and 36 percent of the gross cropped area in 2018-19 against with 29.59 percent and 4.8 percent in 1960-61 respectively. However, the several studies (Sidhu, 2002; Sidhu & Jhol, 2002; Singh & Sidhu, 2006; Singh et al., 2013) claims that the recent scenario is not so encouraging; a sluggish growth in the agriculture sector has been noticed in the state. The growth rate of rice yield has declined from 1.27 percent in 1980s to -0.04 percent in the 1990s, in case of wheat it fall down from 3.00 percent to 1.45 percent in 1990s (Kaur & Sekhon, 2005). One important reason for low yield is that agriculture becomes more input intensive, yield almost reached its potential and further productivity growth slowed. In particular, intensive crop production has threatened the long-term sustainability of agricultural. It directly affects the farm production efficiency level due to over-utilization of input resources that are applied to attain higher yield (Sekhon et al., 2010; Singh et al., 2017).

In particular Punjab, several studies have investigated the extent and determinants of farm efficiency in crop production (Sidhu, 1974; Sidhu & Baanante, 1979; Sidhu & Byerlee, 1992; Singh et al., 1998; Singh et al., 2017). However, only a few studies (Kaur et al., 2010; Sekhon et al., 2010) have addressed this issue at districts level or regions level to see the performance of agricultural sector and regional disparities, but no concert attempts of addressing the issue at micro unit level such as tehsil or block has been observed. Moreover, these studies have provided framework for a particular crop (especially wheat), and have used limited approach to examine the technical efficiency across different regions. Being a small and one of the agriculturally rich state, it is important to see the extent of farm efficient and its regional distribution at micro unit. This will lead to identify the micro level problems of farm sector followed by appropriate policy formation. Therefore, present chapter deals with the issue of differences in production efficiency across tehsils in Punjab, India.

In this chapter, using plot-level panel dataset for the three blocks ranging from 2014-15 to 2016-17 different measures of efficiency such as technical efficiency, scale efficiency, cost efficiency, and allocative efficiency are calculated following the well developed and well established non-parametric approach as developed by Charnes et al. (1978). This chapter particularly focuses on: (i) to estimate the economic efficiency of crop production in Punjab; (ii) to determine the effect of crop diversification on economic efficiency.

This present study makes three distinct contributions to the existing literature. First, it contributes to the literature on production efficiency measures at tehsil-level, which provides some ways to understand the causes of regional diversity. It extends the limited but growing literature on different types of farm efficiencies across tehsils within a state. This tehsil level efficiency measures give an ample opportunity to enhance income/output of the farms at given resources by exploring regional diversity on the part of farmers.

Though, several empirical studies have provided a prominent work on technical inefficiency, yet on area that has received very little consideration in the empirical literature is related to the decomposition analysis of production efficiency. From this viewpoint, this study contributes to the literature on decomposition analysis of overall technical inefficiency across regions. This decomposition of efficiency analysis provides the sources of inefficiencies among different farms.

In the context of scarce agricultural resources, several studies have provided evidences on inadequate use of input resources. However, no study is found that has recommended the amount of each input reduction in order to increase output across regions. In this backdrop, this analysis shed some light on slacks and targets setting appliance to evaluate the way for improvement in the context of inefficient tehsils. For example, if an inefficient tehsil cannot reach their target after proportional addition in output or potential reduction in input, the slacks help to push the inefficient tehsils to reach their target. Thereby, this analysis explains how much proportion of each input has to be reduced for each inefficient tehsil to attain same outcomes. This analysis also assists to limit those inputs which are used in excessively. To carry out this analysis, input output slacks that have been derived from CCR input-oriented DEA based model. Moreover, this study also reveals the ranking of efficient tehsils in Punjab. This information is vital for policy makers to look toward a more suitable direction for production.

The remaining part of the chapter is structured as: - Section 5.2 presents the conceptual and theoretical framework. Section 5.3 represents the efficiency score and scale operations in crops production across tehsils. Section 5.4 presents the efficiency improvement: slacks and targets setting analysis for each tehsil. Section 5.5 presents the performance of farmers' in allocating their agricultural resources across tehsil; the last Section 5.6 represents conclusions and policy implications.

## 5.2 Methodological Frameworks

There are many parametric and non-parametric techniques, which researchers have applied to measure efficiency in the development economics. However, the most popular techniques used to measure farm efficiency are data envelopment analysis (DEA) and stochastic frontier analysis (SFA). SFA is a parametric technique that requires the functional form of the model under consideration and explicitly measures the technical efficiency (Forsund et al., 1980;

Bauer, 1990; Coelli & Battese, 1996). DEA is a non-parametric deterministic technique for measuring the frontier to measure efficiency (Varian, 1984; Chavas & Aliber, 1993; Coelli, 1995).

DEA technique has been used that originally developed by Charnes et al. (1978). DEA method has been preferred over other competing techniques because it can readily produce rich information on technical efficiency and scale efficiency. For crop production efficiency, two most popular DEA models namely CCR[1] and BCC[2] models are used. However, CCR model does not provide any scale effect due to some constraints. Therefore, BCC model is followed, which allows computing the pure technical efficiency and scale efficiency effects, and it is more flexible than the CRS-DEA model.

As it is difficult to give rank or differentiate the most efficient tehsil among the fully efficient tehsils in Punjab with CCR model, therefore the super-efficiency slacks based measurements (SBM) model has been employed. The SBM model has the ability to give ranking to those fully efficient tehsils, which have overall technical efficiency (OTE) score equal to unity.

### *5.2.1 Measurement of farm efficiency: CCR and BCC DEA models*

By exploring regional variations in production efficiency across different tehsil, it finds the overall farm efficiency scores in crop production for each tehsil. Here, technical efficiency (TE) refers to *"the ability of a farm to either produce the maximum feasible output from a given bundle of inputs or to produce the given level of output using minimum amount of inputs" (Coelli et al., 2002).* Overall technical efficiency composes of pure technical efficiency and scale efficiency[3]. Where, pure technical efficiency refers to managerial

[1] CCR model is given by Charnes et al. (1978), and is based on the assumption of constant returns-to-scale.

[2] BCC model is given by Banker et al. (1984), and is based on the assumption of variable returns-to-scale.

[3]The rationing of overall technical efficiency (OTE) to pure technical efficiency (PTE) provides scale efficiency (SE) as shown in the following specification: $SE_k = \frac{TE_{CRS_k}}{TE_{VRS_k}} = \frac{OTE_k}{PTE_k}$; when OTE=PTE than farm unit is said to be scale-efficient. Scale efficiency is described as whether a farm is working at its optimal size or not.

efficiency (application of input utilization) and scale efficiency refers to scale operations of the tehsils. Farm efficiencies scores across tehsils are measured by using the following specification:

i) $\min_{\theta_k, \lambda_1, \lambda_{2,\dots\dots,}\lambda_n, s_i^-, s_r^+}$

$$TE_k = \theta_k - \in \left( \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right)$$

Subject to:

$$ii) \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta_k X_{ik}$$

$$iii) \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = Y_{rk}$$

iv) $s_i^-, s_r^+ \geq 0$

v) $\lambda_j \geq 0, if\ constant\ return\ to\ scale$

$$vi) \sum_{j=1}^{n} \lambda_j = 1, if\ variable\ return\ to\ scale$$

*(i=1,2…m; r =1, 2…s; j=1, 2 …n)* *(5.1)*

In the above specification, *(i=1, 2…m)* and *(r=1, 2…s)* are sets of inputs and output for the farm; *n* is the number of tehsils; $X_{ik}$ is amount of input *i* used by tehsil *k;* $Y_{rk}$ is amount of output *r* produced by tehsil *k*; ∈ is a small positive number, ($s_i^-$) = input slack, ($s_r^+$) = output slack; $\lambda_j$ is non-negative weights for tehsil *j*; $\theta_k$ refers to technical efficiency score of tehsil *k* (within a range from 0<$\theta_k$<1). Given the above specification if $\theta_k = 1$ and $s_i^- = s_r^+ = 0$, then tehsil *k* is Pareto-efficient tehsil, implying that no input excesses and no output shortfalls exist in any optimal solution for that tehsil.

The model comprising *(i–v)* is an identified form of CCR model. It gives Farrell's input-oriented technical efficiency estimation based on the assumption of constant return to scale.

The objective of equation *(i)* is to minimize the inputs, while keeping the output level constant. The model containing *(i–iv)* and *(vi)* is recognized as BCC model that is based on variable return to scale assumption. The main purpose of adding convexity constraint ($\sum_{j=1}^{n} \lambda_j = 1$) is to the CCR model by Banker et al. (1984). Because of this convexity, constraint authorizes that an inefficient DMU is only 'benchmarked' in contrast of similar size DMUs.

*5.2.2 Super-efficiency model*

The Andersen and Petersen's super-efficiency model under CRS assumption is used to resolve ranking issues among the efficient tehsils. In this model efficient tehsils contain any value greater than or equal to unity. This exercise makes it possible to rank the efficient tehsils (i.e., upper super-efficiency scores infers higher rank). To measure super-efficiency scores following specification is used:

$$i) \min_{\theta_k^{super}, \lambda_1, \lambda_{2,\ldots\ldots,} \lambda_n, s_j^-, s_r^+}$$

$$TE_{CRS}^{k,super} = \theta_k^{super} - \in \left( \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right)$$

Subject to:

$$ii) \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta_k^{super} X_{ik}$$

$$iii) \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = Y_{rk}$$

iv) $s_i^-, s_r^+ \geq 0$ (r =1, 2,….s)

v) $\lambda_j (j \neq k) \geq 0$ (i=1, 2…m);(j=1, 2…n) *(5.2)*

Here, all the notations are same as presented in the above section. However, $\theta_k^{super}$ gives ranks to the different tehsils based on their efficiency scores. The higher rank values of $\theta$ shows the most efficient tehsil among the fully efficient tehsils.

*5.2.3 Cost efficiency and allocative efficiency*

*(i) Cost efficiency:* Cost efficiency defines the capability of a firm to obtain a given level of output spending cost-minimizing input prices (Coelli et al., 2002). Fare et al. (1994) explained that the input cost inefficiency is due to wrong selection of the input mix, adoption of inappropriate scale size, input congestion, or to purely technical inefficient. The cost efficiency scores have measures for each tehsil by using the following specification:

$$\underset{\lambda_j x_i}{Minimize}\{CE_k = \sum_{i=1}^{m} p_{ik}x_{ik} \mid \sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{ik}, i = 1, \dots\dots, m, \sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{rk}, r = 1, \dots\dots, s, \lambda_j, x_i \geq 0\} \quad (5.3)$$

In the above model, $CE_k = \sum_{i=1}^{m} p_{ik}x_{ik}$ is the observed aggregate cost of inputs for tehsil $k$; $p_{ik}$ is the price of input $i$ for the tehsil $k$. The above specification assumes that for each tehsil inputs prices ($p_{ik}$, $i=1,\dots,m$) are known and fixed, however they can vary across tehsils. Consider for each tehsil $j$ ($j=1, 2,\dots,n$) a vector $x_j=( x_{1j}, x_{2j} \dots\dots x_{mj})$ showing $m$ inputs used for producing a vector of $s$ outputs $y_j = (y_{1j,} y_{2j,\dots\dots} y_{sj})$; implying that $x_{ik}$ is the observed amount of input $i$ to be used by tehsil $k$; and $y_{rk}$ is the amount of output $r$ produced by tehsil $k$.

Using the above specifications, cost efficiency is ratio of minimum cost to the observed cost defined as below:

$$CE_k = \sum\nolimits_{i=1}^{m} p_{ik}x_{ik}^{*} / \sum\nolimits_{i=1}^{m} p_{ik}x_{ik} \quad (5.4)$$

*(ii) Allocative efficiency:* Allocative efficiency or price efficiency defines the capacity of the farmers to select appropriate mixture of inputs at specified input prices (Farrell, 1957). According to (Yotopoulos & Lau, 1973) a farm is allocatively efficient if it equates the value of the marginal product of each resources employed to the unit cost of that resource.

Therefore, it is examined whether any distinct pattern exists with different regions in Punjab allocative efficiency is measured by using the following equation:

$$AE_k = \frac{CE_k}{TE_k} \tag{5.5}$$

where, $CE_k$ = cost efficiency calculated for tehsil $k$; $TE_k$ = technical efficiency for tehsil $k$

*5.2.4 Impact of crop diversification on economic efficiency*

In order to estimate the link between crop diversification and economic efficiency, very popular and well established ordinary least square (OLS) regression model is used in this chapter. The specification of the model is follows as:

$$TE_i = \alpha_{0i} + \alpha_{1i}SID + \alpha'_{ji}Z + e_i \tag{5.6}$$

where, *TE* is "technical efficiency", *Z* is a vector which includes farm household characteristics such as age, education, gender and major occupation. The coefficient of interest is $\alpha_{1i}$.

**5.3 Data and Specification of Variables**

The data used in this study are retrieved form Comprehensive Scheme for Cost of Cultivation (CCS) of Principal Crops administered by Directorate of Economics and Statistics, Ministry of Agriculture Government of India. In this survey, the data set provides various features of farming across regions of the country since 1970-71. In this dataset, each sample household is surveyed consecutively for three years. However, this study particularly focuses on the recent available data pertaining to the block period 2014-15, 2015-16 and 2016-17 for the Punjab state. For Punjab, plot-level data has been collected from 300 households of 30 tehsils. In CCS data, the sample of households has been divided into five different land-holding size groups. This dataset provides a comprehensive view of the cropping patterns and inputs used by agricultural households. The focus of this study is on two crops: wheat and paddy, which together cover about 89 percent of the sample. However, cotton and maize are also cultivated but they cover only a smaller proportion (13 percent).

To analyze farm-level efficiency in crop production across tehsils in Punjab, the plot-level input-output information at aggregate level are retrieved to show the combined picture of the three block period. Only those cultivators are included who grow selected crops in all the three years. Each tehsil is considered as a DMU has the availability of complete inputs-output information at that level. The tehsils are mainly considered Gurdaspur (T1), Batala (T2), Ajnala (T3), Patti (T4), Dasua (T5), Hoshiarpur 1(T6), Balachaur (T7), Anandpur Sahib (T8), Patiala (T9), Fatehgarh Sahib (T10), Ferozepur (T11), Guruharsahai (T12), Moga (T13), Samrala (T14), Jalandhar (T15), Sultanpurlodhi (T16), Payal (T17), Jagraon (T18), Sangrur (T19), Jalandhar (T20), Malerkotla (T21), Sardulgarh (T22), Mansa (T23), Budhlada (T24), Bathinda (T25), Talwandi Sabo (T26), Malout (Singhewala) (T27), Malout (Shamkot) (T28), Fazilka (T29), Abohar (T30).

For analysis purposes, the physical output of the crops is measured in terms of quintals per hectare including by-products. The by-products are converted into quintals of crops by dividing total value of by-products by crop price (followed Sidhu, 1974). While inputs consists of human labour, machine, seeds, fertilizer, and irrigation machine. Moreover, farmers face different input prices across tehsils, such price variations may be relatively small but it cannot be ruled out. Therefore, price information on inputs is also considered. The description and selection of input-output variables are reported in Table C1 in Appendix C.

Additional variables that could not be considered in the analysis are manure, insecticides, and miscellaneous cost, due to insufficient information availability.

*5.3.1 Descriptive statistics*

Table 5.1 presents the descriptive statistics for variables output, inputs, and input-prices that are used in the estimation. It is noticed that in case of wheat, production varies from 32.4 to 52.4 quintals per-hectare with mean and standard deviation 45.84 and 4.01 respectively. While, in case of paddy, production varies from 36.6 to 84.2 quintals per-hectare, and its mean is 64.9 and standard deviation is 12.4, respectively. The use of all other inputs such as human labour, seed, fertilizers, and irrigation have increased more than double in both crops.

**Table 5.1:** Summary statistics

| Variables | Wheat | | | | | | Paddy | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Obs | Units | Mean | SD* | Min | Max | Obs | Units | Mean | SD* | Min | Max |
| Output Production and by-product**#** | 30 | Qtls/Ha | 45.8 | 4.01 | 32.4 | 52.4 | 29 | Qtls/Ha | 64.9 | 12.4 | 36.6 | 84.2 |
| Inputs | | | | | | | | | | | | |
| Labour@ | 30 | Hrs/Ha | 139 | 56.1 | 89.9 | 367 | 29 | Hrs/Ha | 366 | 62.8 | 311 | 541 |
| Machine$ | 30 | Hrs/Ha | 16.5 | 2.29 | 12.5 | 23.9 | 29 | Hrs/Ha | 14.5 | 2.17 | 10.6 | 19.2 |
| Seeds | 30 | Kg/Ha | 108 | 6.4 | 99 | 122 | 29 | - | - | - | - | - |
| NPK | 30 | Kg/Ha | 234 | 38.4 | 119 | 294 | 29 | Kg/Ha | 187 | 24.6 | 143 | 232 |
| Irrigation# | 30 | Hrs/Ha | 39 | 16.9 | 2.63 | 69.1 | 29 | Hrs/Ha | 233 | 50.3 | 95.3 | 306 |
| Inputs-Prices | | | | | | | | | | | | |
| Labour | 30 | Rs/ha | 6424 | 2608 | 3824 | 17049 | 29 | Rs/ha | 16456 | 2754 | 13491 | 25051 |
| Machine | 30 | Rs/ha | 9054 | 1154 | 6783 | 11603 | 29 | Rs/ha | 6557 | 1260 | 3988.4 | 9523 |
| Seed value | 30 | Rs/ha | 2150 | 244 | 1766 | 2631 | 29 | Rs/ha | 1768 | 368 | 1372.3 | 2917 |
| Fertilizer | 30 | Rs/ha | 4985 | 893 | 2488 | 6755 | 29 | Rs/ha | 3581 | 895 | 2253.5 | 5531 |
| Irrigation machine | 30 | Rs/ha | 647 | 383 | 31.2 | 1753 | 29 | Rs/ha | 2956 | 1155 | 1370.8 | 7324 |

Note:***** Standard Deviation**; @** Human Labour =Family Labour + Attached Labour + Casual Labour; $ Machine = Hired + Own; # Irrigation = Hired Irrigation Machine + Own.

It implies that farmers are using additional amount of inputs i.e. fertilizer, pesticides, labour, and irrigation to obtain higher yield on fixed land. As results diminishing marginal returns occurred, and an increasing input after optimal capacity has been reached leading to smaller increases in output. If this over-utilization input trend continues, it would be difficult to have increasing productivity in the sector. This results is found to be similar as reported in Swarup and Singh, (1989); Kumar and Yadav, (1993); Lal et al. (2004).

## 5.4 Empirical Results of Crops Cultivation

The outcomes of input-oriented CCR and BCC model define by how much can input quantities be proportionally reduced without altering the output quantities produced? Therefore, the tehsils that has a need to reduce their level of inputs usage, are discriminated by using frequency method suggested by Chen and Yeh (1998). To discriminate inefficient tehsils, the efficient tehsils are presented in the reference sets. The higher frequency count tehsils implies that these tehsils are probably good example of "well-rounded performer" with high robustness. Whereas, the lower frequency count tehsils show those tehsils that should not be followed by other inefficient tehsils as their benchmark. Here, the best performer tehsils are identified among the fully efficient tehsils following the Andersen and Petersen (1993) methodology.

### *5.4.1 Efficiency score and scale operations in crops production*

Table 5.2 and Table 5.3 present the estimation of the Equation (5.1). It is found that in case of wheat only 23 (7 out of 30 tehsils) percent tehsils are performing at fully efficient level. It could be inferred that remaining 77 percent tehsils which do not operate at efficiency level need to reduce their input usage by approximately 6.1 percent, to maintain the same level of wheat production as achieved by the other 23 percent of the tehsils. As expected, on an average these tehsils have substantial scope to produce 1.06 times additional output by properly organizing inputs level. While, in case of paddy around 24 percent (7 out of 29) tehsils are operating at frontier level and remaining 76 percent tehsils are producing at an inefficient level. These tehsils are over-utilizing their inputs to the extent of 16.4 percent than required. They have substantial scope to produce 1.19 times more output by applying the same inputs amount.

Table 5.2 and Table 5.3 also present the optimal scale of operation which infers that around 74 percent tehsils in case of wheat and 72.42 percent tehsils in case of paddy are operating under increasing returns-to-scale. As these tehsils are performing below the optimum production scale. It indicates that the production scale could be improved by decreasing the costs of these tehsils.

**Table 5.2:** Estimated efficiency scores of wheat across tehsil from Equation (5.1)

| Tehsil Code | Tehsils | OTE | OTIE | PTE | PTIE | SE | SEI | RTS |
|---|---|---|---|---|---|---|---|---|
| T1 | Gurdaspur | 0.752 | 0.248 | 1.000 | 0.000 | 0.752 | 0.248 | IRS |
| T2 | Batala | 0.924 | 0.076 | 0.982 | 0.018 | 0.941 | 0.059 | IRS |
| T3 | Ajnala | 0.935 | 0.065 | 1.000 | 0.000 | 0.935 | 0.065 | IRS |
| T4 | Patti | 0.929 | 0.071 | 1.000 | 0.000 | 0.929 | 0.071 | IRS |
| T5 | Dasua | 0.849 | 0.151 | 1.000 | 0.000 | 0.849 | 0.151 | IRS |
| T6 | Hoshiarpur 1 | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| T7 | Balachaur | 0.825 | 0.175 | 0.888 | 0.112 | 0.929 | 0.071 | IRS |
| T8 | Anandpur Sahib | 0.885 | 0.115 | 0.955 | 0.045 | 0.926 | 0.074 | IRS |
| T9 | Patiala | 0.920 | 0.080 | 0.938 | 0.062 | 0.981 | 0.019 | IRS |
| T10 | Fatehgarh Sahib | 0.922 | 0.078 | 0.944 | 0.056 | 0.977 | 0.023 | IRS |
| T11 | Ferozepur | 0.971 | 0.029 | 1.000 | 0.000 | 0.971 | 0.029 | IRS |
| T12 | Guruharsahai | 0.991 | 0.009 | 1.000 | 0.000 | 0.991 | 0.009 | IRS |
| T13 | Moga | 0.945 | 0.055 | 0.983 | 0.017 | 0.961 | 0.039 | IRS |
| T14 | Samrala | 0.979 | 0.021 | 0.983 | 0.017 | 0.996 | 0.004 | IRS |
| T15 | Jalandhar | 0.912 | 0.088 | 0.987 | 0.013 | 0.924 | 0.076 | IRS |
| T16 | Sultanpurlodhi | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| T17 | Payal | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| T18 | Jagraon | 0.983 | 0.017 | 1.000 | 0.000 | 0.983 | 0.017 | IRS |
| T19 | Sangrur | 0.987 | 0.013 | 0.988 | 0.012 | 0.999 | 0.001 | IRS |
| T20 | Jalandhar | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| T21 | Malerkotla | 0.938 | 0.062 | 0.953 | 0.047 | 0.983 | 0.017 | IRS |
| T22 | Sardulgarh | 0.959 | 0.041 | 0.969 | 0.031 | 0.989 | 0.011 | IRS |
| T23 | Mansa | 0.985 | 0.015 | 1.000 | 0.000 | 0.985 | 0.015 | IRS |
| T24 | Budhlada | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| T25 | Bathinda | 0.944 | 0.056 | 0.978 | 0.022 | 0.965 | 0.035 | IRS |
| T26 | Talwandi Sabo | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| T27 | Malout(Singhewala) | 0.930 | 0.070 | 0.965 | 0.035 | 0.963 | 0.037 | DRS |
| T28 | Malout(Shamkot) | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| T29 | Fazilka | 0.890 | 0.110 | 1.000 | 0.000 | 0.890 | 0.110 | IRS |
| T30 | Abohar | 0.823 | 0.177 | 0.998 | 0.002 | 0.825 | 0.175 | IRS |
| Mean | - | 0.939 | - | 0.984 | - | 0.955 | - | - |

Notes: OTIE=Overall technical inefficiency=(1-OTE), PTIE=Pure technical inefficiency=(1-PTE), SIE=Scale inefficiency=(1-SE), IRS= increasing returns-to-scale, CRS=constant returns to-scale; and DRS=decreasing returns-to-scale

In particular, these tehsils are not efficiently using their production resources. While, 3 percent of the tehsils in case of wheat and 3.44 percent in case of paddy are working under decreasing returns-to-scale i.e., these tehsils are performing above the optimum scale of production. It reflects that the farmers of these tehsils are over utilizing their inputs in production process.

**Table 5.3:** Estimated efficiency scores of paddy across tehsil from Equation (5.1)

| Tehsil Code | Tehsil | OTE | OTIE | PTE | PTIE | SE | SEI | RTS |
|---|---|---|---|---|---|---|---|---|
| T1 | Gurdaspur | 0.642 | 0.358 | 1.000 | 0.000 | 0.642 | 0.358 | IRS |
| T2 | Batala | 0.683 | 0.317 | 0.851 | 0.149 | 0.803 | 0.197 | IRS |
| T3 | Ajnala | 0.516 | 0.484 | 0.896 | 0.104 | 0.576 | 0.424 | IRS |
| T4 | Patti | 0.681 | 0.319 | 1.000 | 0.000 | 0.681 | 0.319 | IRS |
| T5 | Dasua | 0.691 | 0.309 | 0.916 | 0.084 | 0.754 | 0.246 | IRS |
| T6 | Hoshiarpur 1 | 0.701 | 0.299 | 0.948 | 0.052 | 0.740 | 0.260 | IRS |
| T7 | Balachaur | 0.715 | 0.285 | 0.969 | 0.031 | 0.738 | 0.262 | IRS |
| T8 | Anandpur Sahib | 0.675 | 0.325 | 0.818 | 0.182 | 0.826 | 0.174 | IRS |
| T9 | Patiala | 0.951 | 0.049 | 1.000 | 0.000 | 0.951 | 0.049 | IRS |
| T10 | Fatehgarh Sahib | 0.909 | 0.091 | 1.000 | 0.000 | 0.909 | 0.091 | IRS |
| T11 | Ferozepur | 0.840 | 0.160 | 0.999 | 0.001 | 0.841 | 0.159 | IRS |
| T12 | Guruharsahai | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| T13 | Moga | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| T14 | Samrala | 0.985 | 0.015 | 1.000 | 0.000 | 0.985 | 0.015 | IRS |
| T15 | Jalandhar | 0.674 | 0.326 | 0.934 | 0.066 | 0.722 | 0.278 | IRS |
| T16 | Sultanpurlodhi | 0.966 | 0.034 | 0.984 | 0.016 | 0.981 | 0.019 | IRS |
| T17 | Payal | 0.973 | 0.027 | 0.991 | 0.009 | 0.981 | 0.019 | IRS |
| T18 | Jagraon | 0.947 | 0.053 | 0.965 | 0.035 | 0.981 | 0.019 | IRS |
| T19 | Sangrur | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| T20 | Jalandhar | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| T21 | Malerkotla | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| T22 | Sardulgarh | 0.767 | 0.233 | 0.932 | 0.068 | 0.823 | 0.177 | IRS |
| T23 | Mansa | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| T24 | Budhlada | 0.968 | 0.032 | 0.976 | 0.024 | 0.991 | 0.009 | DRS |
| T25 | Bathinda | 0.881 | 0.119 | 0.952 | 0.048 | 0.926 | 0.074 | IRS |
| T26 | Talwandi Sabo | 0.683 | 0.317 | 0.829 | 0.171 | 0.824 | 0.176 | IRS |
| T27 | Malout(Singhewala) | 0.655 | 0.345 | 0.867 | 0.133 | 0.755 | 0.245 | IRS |
| T28 | Malout(Shamkot) | 0.755 | 0.245 | 0.994 | 0.006 | 0.760 | 0.240 | IRS |
| T29 | Fazilka | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | CRS |
| Mean | - | 0.836 | - | 0.959 | - | 0.869 | - | - |

Notes: OTIE = Overall technical inefficiency = (1-OTE), PTIE=Pure technical inefficiency = (1-PTE), SIE=Scale inefficiency = (1-SE), IRS= increasing returns-to-scale, CRS=constant returns to-scale; and DRS=decreasing returns-to-scale

So, the farmers can downsize their scale of operations to increase their production level. Further, it has been examined that seven tehsils have shown constant returns to scale each for wheat[4] and paddy[5]. This implies that these tehsils are operating at most productive scale

[4]Hoshiarpur 1, Sultanpurlodhi, Payal, Jalandhar, Budhlada, Talwandi Sabo and Malout

operation or lies on flatter portion of the long-run average cost curve. Overall, it implies that only 23 percent in case of wheat and around 24 percent in case of paddy tehsils are operating under correct scale of operations.

According to DEA terminology, these 23 percent tehsils in case of wheat and 24 percent tehsils in case of paddy are called best producer tehsils. The input resources utilization experiences in these tehsils are better. But, remaining 77 percent inefficient tehsils in case of wheat and 76 percent in case of paddy are producing under inappropriate scale size (i.e., too large too small) or performing under poor utilization of inputs. There is a wide difference in technical efficiency across tehsils. Each tehsil performs differently in utilizing the given resources. Thus, higher efficiency gap that exists in across the tehsils can be explained by relatively better use of inputs resources or best practices farmers. These results are consistent with the findings of the earlier (Llewelyn & Williams, 1996; Okello et al., 2019).

*5.4.2 Decomposition of OTE: PTE and SE*

Table 5.2 and Table 5.3 also present the estimation of the decomposition of overall technical efficiency scores. It is found that in case of wheat, nine tehsils namely Gurdaspur, Ajnala, Patti, Dasua, Ferozepur, Guruharsahai, Jagraon, Mansa, and Fazilka are lie on the efficient edge under variable return to scale (VRS) assumption. However, these nine tehsils have been found to be inefficient under constant return to scale (CRS) as their OTE score is less than unity. It indicates that the overall technical inefficiency of these tehsils is due to inappropriate scale size. Furthermore, another 14 tehsils have PTE<1. Out of these 14 tehsils, seven tehsils have PTE score less than the SE score implying that inefficiency of these seven tehsils are due to poor inputs utilization. While, in case of paddy, five tehsils namely Gurdaspur, Patti, Patiala, Fatehgarh Sahib and Samrala are lie on the efficient target under variable return to

[5]Guruharsahai, Moga, Sangrur, Jalandhar, Malerkotla, Mansa, and Fazilka

scale supposition, but these tehsils are inefficient under CRS supposition. From this, it can be concluded that the inefficiency of these five tehsils is resulted by operating on the wrong scale size. The remaining 17 tehsils having PTE score less than unity infer that there exists managerial inefficiency. Out of these 17 tehsils, three tehsils with PTE score less than SE score implies that inefficiency of these tehsils is due to poor input utilization rather than scale size.

Overall, it is observed that inefficiency is resulted from both poor utilization of input mix and inappropriate scale size. When the PTE scores are compare with SE scores, it is found that a greater proportion of overall technical inefficiency is owing to scale inefficiency in case of both crops wheat and rice (see Table C3 and Table C4 in Appendix C). The farmers of these tehsils are not ensuing suitable managing practices and performing under improper scale operations. These findings are consistent with previous literature that says the inefficiency in crop production is caused by inappropriate farming practices viz., pure technical inefficiency and scale inefficiency (Paul et al., 2004; Latruffe et al., 2005; Chen et al., 2011; Ngwira et al., 2012; Hassen et al., 2017).

### *5.4.3 Discrimination of efficient tehsils*

Table 5.4 and Table 5.5 present the frequency or peer count scores of each efficient tehsil. In case of wheat, the tehsils such as Talwandi Sabo and Payal are seemed to have higher frequency scores as compare to other efficient tehsils. They obtained 18 and 17 frequency scores respectively. In the second category, Jalandhar, Budhlada and Hoshiarpur1 are accounted for 8, 6, and 5 frequency counts respectively. And in the third category, two tehsils namely Malout and Sultanpurlodhi are exemplified which have frequency count 3 for each. However, in case of paddy, Sangrur tehsil is more efficient as compared to other efficient tehsils with 12 frequency count followed by Malerkotla and Guruharsahai. In the third category, two tehsils i.e. Moga and Fazilka are efficient tehsils with 3 and 1 frequency count respectively. On the basis of peer count, the higher frequency count tehsils are characterized as efficient producer (or highly robust tehsils).

**Table 5.4:** Peer-weights for inefficient tehsil and peer counts (Wheat)

| Inefficient-tehsils | OTE | Reference Set | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | T6 | T16 | T17 | T20 | T24 | T26 | T28 |
| T1 | 0.752 | 0.124 | - | - | - | 0.186 | 0.338 | - |
| T2 | 0.924 | - | - | 0.166 | - | - | 0.697 | - |
| T3 | 0.935 | - | - | 0.238 | 0.073 | - | 0.556 | - |
| T4 | 0.929 | - | 0.106 | 0.061 | - | 0.160 | 0.528 | - |
| T5 | 0.849 | 0.195 | - | - | 0.652 | - | - | - |
| T7 | 0.825 | 0.230 | - | - | 0.420 | 0.242 | - | - |
| T8 | 0.885 | - | - | 0.028 | - | - | 0.815 | - |
| T9 | 0.920 | - | 0.497 | 0.246 | 0.093 | - | - | 0.144 |
| T10 | 0.922 | - | 0.233 | 0.298 | - | - | - | 0.445 |
| T11 | 0.971 | - | - | 0.507 | - | - | 0.414 | - |
| T12 | 0.991 | - | - | 0.664 | 0.162 | - | 0.148 | - |
| T13 | 0.945 | - | - | 0.697 | - | 0.040 | 0.197 | - |
| T14 | 0.979 | - | - | 0.516 | - | - | 0.446 | - |
| T15 | 0.912 | 0.031 | - | - | 0.482 | 0.364 | - | - |
| T18 | 0.983 | - | - | 0.882 | - | - | 0.081 | - |
| T19 | 0.987 | - | - | 0.891 | - | - | 0.102 | - |
| T21 | 0.938 | - | - | 0.946 | - | - | 0.032 | - |
| T22 | 0.959 | - | - | 0.127 | - | 0.235 | 0.586 | - |
| T23 | 0.985 | - | - | 0.102 | - | - | 0.831 | - |
| T25 | 0.944 | - | - | 0.040 | - | - | 0.876 | - |
| T27 | 0.930 | - | - | 0.039 | 0.424 | - | 0.499 | 0.073 |
| T29 | 0.890 | - | - | - | 0.060 | - | 0.792 | - |
| T30 | 0.823 | 0.064 | - | - | - | - | 0.760 | - |
| Frequency count | | 5 | 3 | 17 | 8 | 6 | 18 | 3 |

Note: values are obtained from solution of CCR model for individual inefficient tehsil.

For better illustrations, the super-efficiency scores for fully efficient tehsils are also estimate (see Table C7 and Table C8 in Appendix C). The super-efficiency scores shows that in case of wheat, Talwandi Sabo is most efficient tehsil with super-efficiency score equal to 2.68. Hoshiarpur1 has occupied the second place having super-efficiency score of 1.30. And in case of paddy, Sangrur tehsil is ranked at the top position with 1.16 super efficiency score, and Mansa has the second place with 1.11 score.

**Table 5.5:** Peer-weights for inefficient tehsil and peer counts (Paddy)

| Inefficient Tehsil | OTE | Reference Set | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | T12 | T13 | T19 | T20 | T21 | T23 | T29 |
| T1 | 0.642 | - | - | - | - | - | 0.462 | 0.022 |
| T2 | 0.683 | 0.742 | - | - | - | - | - | - |
| T3 | 0.516 | - | - | - | 0.567 | - | - | - |
| T4 | 0.681 | 0.596 | - | - | - | - | - | - |
| T5 | 0.691 | 0.722 | - | 0.030 | - | - | - | - |
| T6 | 0.701 | 0.478 | - | 0.258 | - | - | - | - |
| T7 | 0.715 | 0.108 | - | 0.507 | - | 0.118 | - | - |
| T8 | 0.675 | 0.803 | - | - | - | - | - | - |
| T9 | 0.951 | - | - | 0.504 | 0.426 | - | - | - |
| T10 | 0.909 | - | - | 0.722 | - | 0.183 | - | - |
| T11 | 0.840 | - | 0.185 | - | 0.505 | - | 0.111 | - |
| T14 | 0.985 | - | - | 0.439 | 0.527 | - | - | - |
| T15 | 0.674 | 0.382 | - | 0.190 | - | 0.130 | - | - |
| T16 | 0.966 | - | - | 0.376 | 0.603 | - | - | - |
| T17 | 0.973 | - | 0.524 | - | - | 0.306 | 0.130 | - |
| T18 | 0.947 | - | - | - | - | 0.646 | 0.325 | - |
| T22 | 0.767 | - | - | 0.115 | - | 0.668 | - | - |
| T24 | 0.968 | - | - | - | 0.863 | - | 0.179 | - |
| T25 | 0.881 | - | - | 0.113 | 0.580 | - | 0.223 | - |
| T26 | 0.683 | 0.776 | - | - | - | - | - | - |
| T27 | 0.655 | - | - | 0.094 | - | 0.630 | - | - |
| T28 | 0.755 | - | 0.226 | 0.087 | - | 0.424 | - | - |
| Frequency count | | 8 | 3 | 12 | 7 | 8 | 6 | 1 |

Note: values are obtained from solution of CCR model for individual inefficient tehsil.

### *5.4.4 Discrimination of inefficient tehsils*

Table 5.6 and Table 5.7, presents the classification results of inefficient tehsils. The most inefficient tehsils are Gurdaspur, Abohar, Balachaur, Dasua, and Anandpur Sahib in case of wheat, while Ajnala, Gurdaspur, Malout, Jalandhar and Anandpur Sahib are found to be inefficient in case of paddy. The cultivators of these tehsils are worst performers therefore; these tehsils are termed as 'target tehsils'. The inefficient tehsils that have attained Q3<OTE<1 are included in "marginally inefficient" category. The tehsils included in this category are Ferozepur, Samrala, Jagraon, Mansa, Sangrur, and Guruharsahai in case of wheat, while Patiala, Sultanpur, Budhlada, Payal, Samrala are included in case of paddy. It is important to know that these tehsils are marginally inefficient because these tehsils are operating close to the frontier, but they are not producing on the frontier level. These tehsils can enhance their efficiency level in production, and can obtain the status of efficient tehsils by slightly improving their resources utilization process.

**Table 5.6:** Classification of inefficient tehsils (Wheat)

| Category I (OTE<Q1) (Most Inefficient) | Category II (Q1<OTE<Median) (Below Average) | Category III (Median<OTE<Q3) (Above Average) | Category IV (Q3<OTE<1) (Marginally Inefficient) |
|---|---|---|---|
| Gurdaspur (30) | Patiala (25) | Malout (19) | Ferozepur (13) |
| Abohar (29) | Fazilka (24) | Ajnala (18) | Samrala (12) |
| Balachaur (28) | Jalandhar (23) | Malerkotla (17) | Jagraon (11) |
| Dasua (27) | Fatehgarh Sahib (22) | Bathinda (16) | Mansa (10) |
| Anandpur Sahib (26) | Batala (21) | Moga (15) | Sangrur (9) |
| | Patti (20) | Sardulgarh (14) | Guruharsahai (8) |

Notes: 1) The ‘Most Inefficient’ category includes those tehsils which have OTE score below the first quartile; 2) Those tehsils are included in the ‘Below Average’ category whose OTE score lies between first and second quartile; 3) The ‘Above Average’ category consists of the tehsils wherein OTE score lies between median and third quartile; 4) The tehsils with OTE scores above the third quartile are included in the ‘Marginally Inefficient’ category; 5) Figures in brackets are ranks; and 6) Q1= 0.890, Q3=0.971, Median=930.

**Table 5.7:** Classification of inefficient tehsils (Paddy)

| Category I (Most Inefficient) | Category II (Below Average) | Category III (Above Average) | Category IV (Marginally Inefficient) |
|---|---|---|---|
| Ajnala (29) | Patti (24) | Malout (18) | Patiala (12) |
| Gurdaspur (28) | Talwandi Sabo (23) | Sardulgarh (17) | Sultanpurlodhi (11) |
| Malout (27) | Batala (22) | Ferozepur (16) | Budhlada (10) |
| Jalandhar (26) | Dasua (21) | Bathinda (15) | Payal (9) |
| Anandpur Sahib (25) | Hoshiarpur 1 (20) | Fatehgarh Sahib (14) | Samrala (8) |
| | Balachaur (19) | Jagraon (13) | |

Notes: same description in Table 5.6’s note.

## 5.5 Efficiency Improvement: Slacks and Targets Setting Analysis

Table 5.8 and Table 5.9 presents the actual values and target values of input-output variables for 77 percent inefficient tehsils in case of wheat, and around 76 percent inefficient tehsils in case of paddy. The most inefficient tehsil in case of wheat is Gurdaspur with OTE score equal to 0.752. This tehsil can achieve efficient target, if all its inputs level proportionally reduced by 24.8 percent. Even after proportional reduction in all inputs, this tehsil would not become Pareto-efficient. Because non-zero inputs and output slacks[6] exist for this tehsil. To reach Pareto-efficient point, some additional slack modifications are required. The estimations of slacks for all inefficient tehsils show that 15 tehsils have non-zero slacks for human labour, 15 tehsils have non-zero slacks for machine, 4 tehsils have non-zero slacks for seed quantity, 1 tehsil has non-zero slacks for fertilizer, and 20 tehsils have non-zero slacks for irrigation hours. Further, no non-zero slacks have been observed for output (production and by-products). Whereas, in case of paddy the most inefficient tehsil is Ajnala which has OTE score equal to 0.516 implying that the tehsil can achieve efficient target if all its inputs level proportionally reduced by 48.4 percent. Among the 22 inefficient tehsils, 17 tehsils have non-zero slacks for human labour, 14 tehsils have non-zero slacks for machine, 12 tehsils have non-zero slacks for seed value, 11 tehsils have non-zero slacks for fertilizer, and 11 tehsils have non-zero slacks for irrigation hours. In other words, it can be concluded that majority of the inefficient tehsils need to reduce their irrigation hours per hectare, use of human hours per hectare, and quantity of fertilizers to attain the same level of output.

To obtain slacks and targets setting analysis across tehsil OTE scores has used with slacks values and actual values are used. The target point $(\hat{x}, \hat{y})$ is defined by the following equations:

$$\hat{x}_{ik} = \theta_k^* x_{ik} + s_i^- \qquad i = 1,2, \dots\dots, m$$

$$\hat{y}_{rk} = y_{rk} - s_r^+ \qquad r = 1,2, \dots\dots, s$$

[6] The slacks represent only the leftover portions after reductions in inputs or output. These slacks take place only for inefficient tehsils and give an informative or valuable suggestion to the inefficient tehsils by which an inefficient tehsils can improve and become efficient tehsils. The slacks indicate how these inefficient farms can improve their operations and their efficiency (Jacobs et al., 2006). If a tehsil cannot reach to its efficient target, slacks help to push the tehsil to reach their target (Ozcan, 2008).

where, $\hat{x}_{ik}$ = target input i for k-th tehsil, $\hat{y}_{rk}$ = target output r for k-th tehsil; $x_{ik}$ = actual input i for k-th tehsil; $y_{rk}$ = actual output r for k-th tehsil; $\theta_k^*$ = OTE score of k-th tehsil; "$s_i^-$= optimal input slacks; and $s_r^+$= optimal output slacks. ($\Delta x_{ik} = x_{ik} - \hat{x}_{ik}$) presents the amount of input i to be reduced, while ($\Delta y_{rk} = y_{rk} - \hat{y}_{rk}$) presents the quantity of output r to be increased to push the inefficient tehsils to efficient frontier. The potential input reduction is for input *i* and potential output addition for output *r* is obtained by ($\Delta x_{ik}/x_{ik}$) ×100 and ($\Delta y_{rk}/y_{rk}$) ×100, respectively.

The percentage of potential input reduction and the percentage of output addition implies that most inefficient tehsil in case of wheat, which is Gurdaspur, needs to reduce its human labour hours per-hectare use by 25.5 percent, machine use by 24.8 percent, seed quantity per hectare by 34.1 percent, fertilizer amount by 24.8 percent, and the irrigation hours per hectare by 24.8 percent to achieve frontier level. In case of paddy, the tehsil Ajnala needs to reduce its human labour hours per hectare use by 55.84 percent, machine use by 49.84 percent, seed value per hectare by 62.25 percent, fertilizer amount by 48.41 percent, and the irrigation hours per hectare by 54.46 percent. The similar explanations can be obtained for the other inefficient tehsils. The results are consistent with the findings of Zhang et al., (2015) who studied productivity effect and overuse of pesticides in China. Similarly, the findings of Kumbhakar (1994) reported that in West Bengal, India.

**Table 5.8:** Actual and target values of input and output variables and potential reduction in inputs and potential addition in outputs (Wheat)

| Inefficient-tehsils | OTE | Actual values of output and inputs variables | | | | | | Target values of output and inputs variables | | | | | | Potential Input reduction (%) | | | | | Potential output addition (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Y1 | X1 | X2 | X3 | X4 | X5 | Y1 | X1 | X2 | X3 | X4 | X5 | X1 | X2 | X3 | X4 | X5 | Y |
| T1 | 0.752 | 32.4 | 131 | 12.8 | 111 | 191 | 21.4 | 32.4 | 97.5 | 9.66 | 73 | 143 | 16.1 | 25.5 | 24.8 | 34.1 | 24.8 | 24.8 | 0 |
| T2 | 0.924 | 44.6 | 140 | 18.8 | 103 | 227 | 55 | 44.6 | 95.9 | 14.1 | 95.1 | 210 | 8.61 | 31.5 | 25.2 | 7.67 | 7.61 | 84.3 | 0 |
| T3 | 0.935 | 44.2 | 99.3 | 18.8 | 101 | 225 | 40.9 | 44.2 | 92.9 | 14.2 | 94.2 | 210 | 14 | 6.48 | 24.4 | 6.53 | 6.49 | 65.8 | 0 |
| T4 | 0.929 | 43.7 | 109 | 13.9 | 101 | 224 | 38.0 | 43.7 | 101 | 12.9 | 94.2 | 208 | 16.4 | 7.19 | 7.12 | 7.14 | 7.14 | 56.9 | 0 |
| T5 | 0.849 | 38.8 | 142 | 18.0 | 107 | 164 | 43.1 | 38.8 | 107 | 13.9 | 90.9 | 139 | 33.2 | 24.7 | 22.7 | 15.1 | 15.1 | 22.9 | 0 |
| T7 | 0.825 | 41.8 | 159 | 16.5 | 122 | 202 | 48.1 | 41.8 | 131 | 13.6 | 97.5 | 166 | 38.8 | 17.5 | 17.6 | 20.1 | 17.5 | 19.4 | 0 |
| T8 | 0.885 | 44.1 | 367 | 15.7 | 107 | 224 | 65.4 | 44.1 | 96.9 | 13.7 | 94.7 | 198 | 3.3 | 73.6 | 13.2 | 11.5 | 11.5 | 95 | 0 |
| T9 | 0.920 | 46.4 | 102 | 15.4 | 111 | 262 | 36.3 | 46.4 | 93.7 | 14.2 | 102 | 241 | 34.3 | 8.01 | 7.98 | 7.93 | 7.97 | 5.32 | 0 |
| T10 | 0.922 | 45.7 | 98.8 | 15.4 | 113 | 286 | 43.5 | 45.7 | 91.1 | 14.2 | 104 | 249 | 25.7 | 7.77 | 7.81 | 7.8 | 13 | 41.0 | 0 |
| T11 | 0.971 | 46.4 | 103 | 18.2 | 100 | 248 | 43.6 | 46.4 | 94.6 | 15.2 | 97.3 | 240 | 21.7 | 8.19 | 16.6 | 2.93 | 2.91 | 50.1 | 0 |
| T12 | 0.991 | 47.8 | 93.7 | 16.9 | 101 | 254 | 45.8 | 47.8 | 92.9 | 16.2 | 100 | 252 | 33.7 | 0.88 | 3.74 | 0.89 | 0.87 | 26.6 | 0 |
| T13 | 0.945 | 46.4 | 145 | 16.2 | 102 | 269 | 47.6 | 46.4 | 92.9 | 15.3 | 96.2 | 254 | 31.0 | 35.9 | 5.49 | 5.48 | 5.51 | 34.8 | 0 |
| T14 | 0.979 | 48.6 | 133 | 18.4 | 104 | 256 | 52.4 | 48.6 | 99.2 | 15.8 | 102 | 251 | 22.2 | 25.3 | 14.0 | 2.12 | 2.07 | 57.6 | 0 |
| T15 | 0.912 | 42.8 | 116 | 14.4 | 112 | 204 | 55.1 | 42.8 | 106 | 13.2 | 95.3 | 186 | 39.2 | 8.74 | 8.80 | 15.1 | 8.82 | 28.8 | 0 |
| T18 | 0.983 | 47.3 | 151 | 17.5 | 99 | 274 | 47.4 | 47.3 | 90.7 | 16.0 | 97.3 | 269 | 36.2 | 40.0 | 8.24 | 1.68 | 1.68 | 23.7 | 0 |
| T19 | 0.987 | 48.9 | 129 | 16.8 | 102 | 280 | 47.9 | 48.9 | 93.9 | 16.5 | 101 | 276 | 36.6 | 27 | 1.84 | 1.37 | 1.29 | 23.6 | 0 |
| T21 | 0.938 | 47.9 | 128 | 17.4 | 105 | 294 | 53.8 | 47.9 | 90.9 | 16.3 | 98.1 | 276 | 38.6 | 29 | 6.32 | 6.28 | 6.26 | 28.2 | 0 |
| T22 | 0.959 | 49.0 | 160 | 15.2 | 110 | 246 | 69.1 | 49.0 | 115 | 14.5 | 105 | 235 | 19.3 | 28.3 | 4.09 | 4.11 | 4.11 | 72.1 | 0 |
| T23 | 0.985 | 48.5 | 185 | 16.7 | 105 | 226 | 28.3 | 48.5 | 106 | 15.1 | 104 | 223 | 6.32 | 43 | 9.40 | 1.42 | 1.55 | 77.6 | 0 |
| T25 | 0.944 | 47.8 | 164 | 18.2 | 109 | 229 | 22.9 | 47.8 | 105 | 14.8 | 103 | 216 | 3.93 | 36.1 | 18.4 | 5.6 | 5.6 | 82.8 | 0 |
| T27 | 0.930 | 51.3 | 114 | 19.0 | 122 | 237 | 21.4 | 51.3 | 106 | 16.9 | 113 | 221 | 19.9 | 6.93 | 11.3 | 6.99 | 7.0 | 6.97 | 0 |
| T29 | 0.890 | 44.3 | 114 | 16.1 | 107 | 220 | 9.05 | 44.3 | 97.0 | 13.8 | 95.6 | 196 | 4.39 | 14.8 | 14.3 | 11.0 | 11.1 | 51.5 | 0 |
| T30 | 0.823 | 42.5 | 202 | 23.9 | 120 | 225 | 5.73 | 42.5 | 104 | 13.3 | 92.9 | 185 | 4.72 | 48.7 | 44.4 | 22.6 | 17.6 | 17.7 | 0 |

Notes: Y= production and by products, x1=human labour, x2= machine, x3 = seed quantity, x4=fertilizer, x5=irrigation.

**Table 5.9:** Actual and target values of input and output variables and potential reduction in inputs and potential addition in outputs (Paddy)

| Inefficient-tehsils | OTE | Actual values of output and inputs variables | | | | | | Target values of output and inputs variables | | | | | | Potential Input reduction (%) | | | | | Potential output addition (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Y1 | X1 | X2 | X3 | X4 | X5 | Y1 | X1 | X2 | X3 | X4 | X5 | X1 | X2 | X3 | X4 | X5 | Y |
| T1 | 0.642 | 36.59 | 496.5 | 10.76 | 1564 | 142.7 | 122.2 | 36.59 | 152.1 | 6.356 | 922.3 | 91.53 | 78.42 | 69.37 | 40.95 | 41.04 | 35.84 | 35.84 | 0 |
| T2 | 0.683 | 57.78 | 540.1 | 13.18 | 1864 | 197.2 | 291.4 | 57.78 | 240.1 | 9.009 | 1142 | 130.2 | 170.4 | 55.54 | 31.66 | 38.71 | 33.97 | 41.52 | 0 |
| T3 | 0.516 | 39.65 | 399.0 | 12.50 | 2494 | 166.2 | 258.9 | 39.65 | 176.2 | 6.269 | 941.5 | 85.75 | 117.9 | 55.84 | 49.84 | 62.25 | 48.41 | 54.46 | 0 |
| T4 | 0.681 | 46.42 | 380.0 | 10.63 | 2273 | 165.7 | 266.9 | 46.42 | 192.9 | 7.237 | 917.6 | 104.6 | 136.9 | 49.24 | 31.89 | 59.63 | 36.86 | 48.72 | 0 |
| T5 | 0.691 | 58.77 | 390.0 | 13.44 | 1670 | 194.8 | 305.7 | 58.77 | 243.8 | 9.282 | 1153 | 132.3 | 174.1 | 37.49 | 30.94 | 30.93 | 32.10 | 43.04 | 0 |
| T6 | 0.701 | 58.92 | 540.5 | 14.58 | 1553 | 221.0 | 288.9 | 58.92 | 241.3 | 10.23 | 1089 | 131.4 | 180.8 | 55.36 | 29.85 | 29.85 | 40.57 | 37.43 | 0 |
| T7 | 0.715 | 60.57 | 356.9 | 16.25 | 1465 | 197.3 | 262.5 | 60.57 | 243.8 | 11.62 | 1048 | 136.1 | 187.7 | 31.70 | 28.50 | 28.50 | 31.03 | 28.50 | 0 |
| T8 | 0.675 | 62.56 | 446.6 | 14.44 | 1890 | 231.1 | 278.3 | 62.56 | 260.0 | 9.754 | 1237 | 141.0 | 184.5 | 41.78 | 32.47 | 34.55 | 38.98 | 33.71 | 0 |
| T9 | 0.951 | 72.15 | 336.5 | 14.49 | 1470 | 165.3 | 244.0 | 72.15 | 301.5 | 13.35 | 1398 | 157.1 | 227.2 | 10.43 | 7.868 | 4.948 | 4.948 | 6.909 | 0 |
| T10 | 0.909 | 75.51 | 336.2 | 16.48 | 1408 | 200.3 | 258.6 | 75.51 | 302.4 | 14.88 | 1279 | 169.8 | 235.0 | 10.06 | 9.685 | 9.122 | 15.23 | 9.122 | 0 |
| T11 | 0.84 | 58.44 | 345.9 | 13.14 | 1591 | 155.6 | 196.6 | 58.44 | 251.8 | 9.784 | 1336 | 130.7 | 165.1 | 27.22 | 25.56 | 16.03 | 16.03 | 16.03 | 0 |
| T14 | 0.985 | 73.82 | 351.1 | 19.12 | 1501 | 163.1 | 286.1 | 73.82 | 311.3 | 13.36 | 1478 | 160.6 | 230.5 | 11.35 | 30.12 | 1.539 | 1.539 | 19.43 | 0 |
| T15 | 0.674 | 56.19 | 340.8 | 14.33 | 1681 | 190.1 | 277.8 | 56.19 | 229.8 | 9.665 | 1053 | 128.2 | 165.7 | 32.57 | 32.57 | 37.36 | 32.57 | 40.35 | 0 |
| T16 | 0.966 | 73.78 | 327.0 | 15.40 | 1571 | 166.1 | 269.6 | 73.78 | 313.6 | 13.11 | 1517 | 160.3 | 228.8 | 4.106 | 14.87 | 3.44 | 3.44 | 15.13 | 0 |
| T17 | 0.973 | 76.00 | 326.1 | 17.15 | 1583 | 185.6 | 206.0 | 76.00 | 310.9 | 13.67 | 1540 | 180.5 | 200.4 | 4.682 | 20.33 | 2.749 | 2.749 | 2.749 | 0 |
| T18 | 0.947 | 76.88 | 329.9 | 14.51 | 1793 | 214.6 | 191.2 | 76.88 | 312.3 | 13.01 | 1638 | 191.6 | 181.1 | 5.311 | 10.32 | 8.631 | 10.71 | 5.311 | 0 |
| T22 | 0.767 | 63.33 | 334.0 | 14.59 | 2517 | 231.5 | 213.1 | 63.33 | 256.2 | 11.05 | 1208 | 155.4 | 163.4 | 23.30 | 24.29 | 52.01 | 32.86 | 23.30 | 0 |
| T24 | 0.968 | 74.03 | 371.3 | 14.71 | 2049 | 169.9 | 215.8 | 74.03 | 323.9 | 11.86 | 1774 | 164.4 | 208.8 | 12.76 | 19.37 | 13.41 | 3.248 | 3.248 | 0 |
| T25 | 0.881 | 67.11 | 326.7 | 17.11 | 1769 | 171.1 | 213.7 | 67.11 | 287.7 | 11.24 | 1543 | 150.7 | 188.2 | 11.93 | 34.3 | 12.77 | 11.93 | 11.93 | 0 |
| T26 | 0.683 | 60.43 | 374.4 | 13.79 | 2917 | 214.5 | 282.2 | 60.43 | 251.1 | 9.422 | 1195 | 136.2 | 178.2 | 32.93 | 31.66 | 59.05 | 36.5 | 36.85 | 0 |
| T27 | 0.655 | 58.55 | 361.7 | 19.22 | 1883 | 229.4 | 229.4 | 58.55 | 236.9 | 10.18 | 1120 | 144.0 | 150.2 | 34.51 | 47.07 | 40.53 | 37.23 | 34.51 | 0 |
| T28 | 0.755 | 59.23 | 358.4 | 14.55 | 1502 | 187.8 | 210.0 | 59.23 | 240.8 | 10.62 | 1135 | 141.9 | 158.7 | 32.82 | 27.00 | 24.45 | 24.45 | 24.45 | 0 |

Notes: Y= production and by products, x1=human labour, x2= machine, x3 = seed value, x4=fertilizer, x5=irrigation.

### 5.6 Allocative and Cost Efficiency Analyses

Table 5.10 presents the estimation of Equations (5.4) and Equation (5.5). The results show that only 3.33 percent in case of wheat and 3.44 percent in case of paddy tehsils are found to be allocative efficient. These efficient tehsils are operating with the optimal combination of inputs at given input prices. It indicates that majority of the tehsils are using inappropriate combinations of input-mix at given input prices. Further, only 3 percent of the tehsils are cost efficient in both crops. Further, 23 percent inefficient tehsils, in case of wheat; and 15 percent in case of paddy are operating under higher cost of production. The inefficient tehsils can minimize their production cost by 27.3 percent in case of wheat; and 31 percent in case of paddy to achieve the same level of output. They can reduce their costs by carefully selecting the appropriate combinations of inputs at given input prices. In the results, in case of wheat- Jalandhar; and in case of paddy- Malerkotla both are fully allocative efficient tehsils showing that they have efficient farmers in crop cultivation. Therefore, other farmers need to learn from these farmers to improve their efficiency level. These results are consistent with existing studies that showed that the majority of rice farms are unable to apply correct mixer of inputs that is necessary for achieving cost minimization due to which they are both allocatively and economically inefficient (Watkins et al., 2014).

As mentioned, only Jalandhar tehsil (in case of wheat) and Malerkotla tehsil (in case of paddy) are fully profit-efficient[7]. The tehsils that have technical efficiency scores greater than allocative efficiency (TE>AE) scores, show the inability of the farmers to use optimum mix of resources to minimize cost at given inputs. If TE<AE, it implies that farmers are cultivating with exploitative use of input resources. The results presented in Table 5.10 show that the two tehsils in case of wheat and 14 tehsils in case of paddy have technical efficiency scores less than allocative efficiency scores. In case of paddy, most of the tehsils have

[7]A farm is said to be fully profit efficient if and only if that farm is technically, allocatively and scale efficient (Forsund et al., 1980).

TE<AE, which specifies that farmers of these tehsils are using input resources in an inefficient manner.

**Table 5.10:** Estimated results from Equations 5.4 and Equation 5.5 for wheat and rice

| Tehsils | Wheat | | | Paddy | | |
|---|---|---|---|---|---|---|
| | TE | (AE =CE/TE) | (CE=TE*AE) | TE | (AE =CE/TE) | (CE=TE*AE) |
| T1 | 0.752 | 0.794 | 0.597 | 0.530 | 0.595 | 0.315 |
| T2 | 0.924 | 0.778 | 0.718 | 0.691 | 0.669 | 0.462 |
| T3 | 0.935 | 0.856 | 0.800 | 0.536 | 0.822 | 0.441 |
| T4 | 0.929 | 0.859 | 0.798 | 0.681 | 0.736 | 0.501 |
| T5 | 0.849 | 0.821 | 0.697 | 0.694 | 0.896 | 0.622 |
| T6 | 1.000 | 0.472 | 0.472 | 0.976 | 0.536 | 0.523 |
| T7 | 0.825 | 0.798 | 0.658 | 0.684 | 0.881 | 0.602 |
| T8 | 0.885 | 0.381 | 0.337 | 0.675 | 0.834 | 0.536 |
| T9 | 0.920 | 0.830 | 0.764 | 0.867 | 0.862 | 0.748 |
| T10 | 0.922 | 0.765 | 0.706 | 0.900 | 0.813 | 0.731 |
| T11 | 0.971 | 0.812 | 0.788 | 0.700 | 0.943 | 0.660 |
| T12 | 0.991 | 0.820 | 0.813 | 1.000 | 0.983 | 0.983 |
| T13 | 0.945 | 0.723 | 0.683 | 0.979 | 0.890 | 0.871 |
| T14 | 0.979 | 0.771 | 0.755 | 0.839 | 0.801 | 0.672 |
| T15 | 0.912 | 0.860 | 0.785 | 0.668 | 0.884 | 0.591 |
| T16 | 1.000 | 0.837 | 0.837 | 0.907 | 0.778 | 0.706 |
| T17 | 1.000 | 0.773 | 0.773 | 0.935 | 0.878 | 0.821 |
| T18 | 0.983 | 0.686 | 0.675 | 0.941 | 0.905 | 0.852 |
| T19 | 0.987 | 0.738 | 0.728 | 1.000 | 0.847 | 0.847 |
| T20 | 1.000 | 1.000 | 1.000 | 0.986 | 0.885 | 0.872 |
| T21 | 0.938 | 0.727 | 0.681 | 1.000 | 1.000 | 1.000 |
| T22 | 0.959 | 0.740 | 0.710 | 0.768 | 0.904 | 0.694 |
| T23 | 0.985 | 0.689 | 0.678 | 1.000 | 0.956 | 0.956 |
| T24 | 1.000 | 0.743 | 0.743 | 0.913 | 0.836 | 0.764 |
| T25 | 0.944 | 0.759 | 0.717 | 0.834 | 0.966 | 0.805 |
| T26 | 1.000 | 0.889 | 0.889 | 0.778 | 0.798 | 0.620 |
| T27 | 0.930 | 0.922 | 0.857 | 0.656 | 0.918 | 0.602 |
| T28 | 1.000 | 0.804 | 0.804 | 0.678 | 0.991 | 0.671 |
| T29 | 0.890 | 0.893 | 0.794 | 0.595 | 0.929 | 0.553 |
| T30 | 0.823 | 0.666 | 0.548 | - | - | - |

Note: TE= Technical efficiency; AE= Allocative efficiency; CE=Cost efficiency.

### 5.7 Impact of Crop Diversification on Economic Efficiency

Table 5.11 presents the estimation of Equation (5.6). From the estimation, it is observed that the crop diversification has a positive and statistical significant impact on the technical efficiency as well as on cost efficiency in case of both crops-wheat and paddy. It implies that as a farmer becomes more diversified, their economic efficiency significantly increases.

These results are consistent with the findings Coelli and Fleming (2004) that crop diversification has significantly improves technical efficiency of farms in Guinea, but this results does not support the outcomes by Llewelyn and Williams (1996) who found that crop diversification significantly led to greater technical inefficiencies in East-Java, Indonesia.

**Table 5.11:** Estimation of Equation (5.6)

| Variables | Wheat | | Paddy | |
|---|---|---|---|---|
| | Technical efficiency | Cost efficiency | Technical efficiency | Cost efficiency |
| Age | -0.0002<br>(0.0006) | -0.0008<br>(0.0015) | 0.0009<br>(0.0020) | 0.0016<br>(0.0021) |
| Female | 0.00096<br>(0.0305) | 0.0272<br>(0.0705) | -0.0937<br>(0.0936) | -0.0578<br>(0.0997) |
| Education | | | | |
| Up to primary | -0.0284<br>(0.02781) | 0.0348<br>(0.0643) | -0.0357<br>(0.0866) | -0.1324<br>(0.0922) |
| Up to secondary | -0.0090<br>(0.03030) | 0.0309<br>(0.0701) | -0.0869<br>(0.0953) | -0.1853<br>(0.1015) |
| Secondary | -0.0168<br>(0.0337) | 0.0639<br>(0.0781) | -0.0124<br>(0.1241) | -0.2057<br>(0.1321) |
| Post-Secondary | -0.0839<br>(0.0598) | 0.0763<br>(0.1385) | 0.0501<br>(0.1957) | 0.0205<br>(0.2083) |
| Major occupation | | | | |
| Crop production | -0.0400<br>(.03452) | 0.0551<br>(0.0798) | -0.1811<br>(0.1025) | -0.1875<br>(0.1091) |
| Non-crop agriculture | -0.0095<br>(0.0473) | -0.0188<br>(0.0740) | -0.0441<br>(0.1012) | -0.0699<br>(0.1078) |
| Other work | -0.0313<br>(0.0473) | -0.0417<br>(0.1094) | -0.0532<br>(0.1389) | -0.0129<br>(0.1479) |
| HHI | .6570***<br>(0.1972) | 1.2412***<br>(0.4563) | 1.8883***<br>(0.9205) | 2.0466***<br>(0.9800) |
| R-squared | 54 | 37 | 50 | 39 |
| Observation | 30 | 30 | 29 | 29 |

Note: *** p<0.01, ** p<0.05, * p<0.1 represent the significance level at 1%, 5%, and 10% respectively, and Standard errors are in the parentheses.

## 5.8 Conclusions

The injudicious use of inputs affect sustainability of agriculture, specifically in developing countries where agricultural resources are scarce and adopting better technologies is not feasible due to financially weak farmers. In this context, three key issues are address in this chapter; (i) to estimate the economic efficiency of crop production in Punjab; (ii) to determine the effect of crop diversification on economic efficiency.

It is found that overall around 23 percent tehsils are operating at flatter portion of long-run average cost curve, and remaining 77 percent tehsils are performing above or below the optimum scale of production. Further, it found a greater portion of inefficiency is mainly attributed by scale inefficiency rather than pure technical inefficiency. Additionally, it is observed that tehsils are allocating their inputs resources with exploitative manner due to which, they fail to choose a suitable combination of inputs which is necessary to achieve cost minimization. Moreover, it is also found that 23 percent tehsils in case of wheat; and 15 percent inefficient tehsils are working under higher cost of production.

Thus, the study suggests that there is substantial scope for upgrading in the performance of inefficient tehsils by carefully choosing combination of inputs at given input prices and scale size. The inefficient tehsils need better guidance and information in selecting the appropriate combination of inputs at given input prices. Moreover, it is also pointed out that here the efficiency is measured at the farm level in Punjab, this farm-level information may show the ways to formulate appropriate efficiency generating policies.

# *Chapter-6*

# *Major Findings and Policy Implications*

# CHAPTER-6

***Major Findings and Policy Implications***

# Chapter 6

# Major Findings and Policy Implications

## 6.1 Introduction

In most of the developing countries like India, crop diversification is considered as an important strategy to improve agricultural development and rural development. It is argued that adaptation of crop diversification not only enhance the agricultural growth but it provides resilience to agricultural production from harmful shocks also i.e., variation in rainfall and temperature. Therefore, this study attempted to delineate the extent and role of crop diversification particularly in Punjab. Therefore, considering the key role of crop diversification, this study dealt with following three specific objectives:- (i) to explore the trend and pattern of crop diversification in Punjab; and identified the factors those determine crop diversification; (ii) to assess the impact of weather shocks on crop productivity; and examine the adaptation benefits of crop diversification against these weather shocks; (iii) to estimate the economic efficiency of crop production in Punjab; and determine the effect of crop diversification on economic efficiency.

## 6.2 Major Findings

### *6.2.1 Findings based on third chapter (A Temporal Analysis of Crop Diversification in Punjab's Agriculture)*

As the key objectives of this chapter are to explore the trend and pattern of crop diversification in Punjab; and to identify the factors those determine crop diversification in Punjab. The major findings of the analysis are listed below-

1) The results reveal that due to the advent of green revolution the cropping pattern has been changing in Punjab since the mid-60s. The green revolution has shifted focus of the cultivators of Punjab towards a few crops mainly wheat-rice rotation due to favourable conditions available for these crops in the state. Wheat and rice crops are being sown on maximum area in Punjab. As these crops involve lower risk and more profitability as compared to other competitive crops. The crops such as maize, sugarcane, potato, and onion also experienced mild growth.
2) The both- multiannual version (RCat) and binary version (RCt) of indices have found the declining value from 1 to 0.71 for area, 1 to 0.70 for production, and 1 to 0.91 for productivity implying that the mobility of the crops within the overall distribution is virtually lower.
3) It is found that key components responsible for the change in total production are area effect and yield effect for wheat and rice. Thus, it observed that decline in crop diversification has been influenced by the increasing contribution of the area effect and yield effect of land to the total production of crops wheat and rice.
4) It is found that the key determinants responsible for increased the degree of crop diversification are number of market per/ha, length of road per/ha, urbanization, and number of tractor per/ha. Whereas amount of fertilizer and intensity of irrigation are negatively linked to degree of crop diversification.

*6.2.2 Findings based on fourth chapter (Weather Shocks, Crop Productivity, and Crop Diversification: Adaptation Practices in Punjab)*

The objective of this chapter is to assess the impact of weather shocks on crop productivity; and to examine the adaptation benefits of crop diversification against the weather shocks. Cultivators are required to protect themselves against these extreme shocks by adopting several ex-ante and ex-post risk-copping appliances. Therefore, in this context the present study made an effort not only to assess the effects of weather shocks (delayed monsoon), but to find out the role of crop diversification as an adaptation strategy to cope of with weather shocks (delayed monsoon).

1) The estimations show that the weather shocks had a negative impact on crop productivity. It found that one standard deviation delay in monsoon onset lowers 3.94 percent agricultural productivity in comparison to the normal arrival of monsoon day.
2) It is found that positive and significant coefficient (0.17) of interaction term of monsoon onset day with crop diversification indicates that the crop diversification assists in the negative effects of delayed monsoon arrival on crop productivity.
3) Further, it is found that overall results hold even after controlling other additional variables such as share of crop irrigated area, fertilizer.

*6.2.3 Findings based on fifth chapter (Economic Efficiency of Agriculture in Punjab)*

The injudicious use of inputs affect sustainability of agriculture especially in developing countries where agricultural resources are scarce; and adopting better technologies is not feasible. The set objectives of this chapter were to estimate the economic efficiency of crop production in Punjab; and to determine the effect of crop diversification on economic efficiency.

1) It was found that around 23 percent tehsils in Punjab are operating at flatter portion of long-run average cost curve, and remaining 77 percent tehsils are performing above or below the optimum scale of production.

2) Further, it observed inefficiency is resulted from both-poor utilization of inputs mix and inappropriate scale size. But, a greater portion of inefficiency is mainly attributed by scale inefficiency rather than pure technical inefficiency.

3) The percentage of potential input reduction and the percentage of potential output addition implies that most of the tehsils needs to reduce inputs such as human labour hours per hectare, use of machine, fertilizer amount, and irrigation hours per hectare.

4) Additionally, it is also found that tehsils in Punjab failed to choose a suitable combination of inputs which is necessary to achieve cost minimization. Around 23 percent tehsils in case of wheat; and 15 percent tehsils in case of paddy are found inefficient. Therefore, there is substantial scope for upgrading in the performance of inefficient tehsils by carefully choosing combination of inputs at given input prices and scale size.

5) Further, it is observed that crop diversification has a positive and significant impact on the technical efficiency, implying that if farmers become more diversified their economic efficiency significantly increases.

## 6.3 Policy Implications

The findings of the present study have interesting policy implications as it is already said that crop diversification considered as one of the important strategies for sustainable agriculture in developing economics, policy makers have high expectation on crop diversification an its propagation at increasing pace on the basis of the findings of the present study following polices measures are suggested that can be adopted and implemented for enhancement of level of crop diversifications in Punjab in particular, and in India, in general-

1. **Redesigning the MSP Policy:**

   Farmers are consistently devoting maximum their crop area for wheat and rice crop only. It is mainly the result of MSP backed agricultural policy. This encourages the farmers to put larger share of their area under two crops wheat and paddy only. Therefore, it is suggested to review the MSP policy. Here, gradual withdrawal for MSP for wheat and rice crops be sought to reinforce the crop diversification and to demotivate discourage the farmers for doing specialized in cropping of wheat-rice rotation.

2. **Providing incentives for Oilseed and Pulses Cultivation:**

   Especially oilseed and pulses are very vulnerable to climate and other factors. Therefore, it's need of the hour to provide direct incentives to the cultivators of these crops as subsidize insurance policy, low cost inputs, assured prices, and market. Moreover, It also observed the positive and significant coefficient of HHI in regression analysis, therefore it is suggested that to provide more incentives to encourage the farmers for producing multiple crops. It is because if farmers are become more diversified their economic efficiency significantly increases.

3. **Educating Farmers:**

   No doubt area effect and yield effect are showing positive growth trend for the specialized crops; but soon it reaches to the diminishing return due to severe loss of nutrition value of soil and emergence of resistant pests. Therefore, educating the farmers for sowing different crops becomes inevitable. For this, it is suggested to establish training and education centre at tehsil level especially for educating the farmers for growing different crops and its benefits.

4. **Crop Diversification Oriented Infrastructure:**

   Since market per hectare and length of road per hectare are found positively impacting the level of crop diversification, so it suggested that infrastructure aspects in Punjab should be taken on priority. This may include building of connecting roads from farms to markets. Similarly, food processing units should be established at local levels.

5. **Region-specific Climate Warning System:**

   Weather shocks are very challenging for cultivators especially irregularity of monsoon/rains. Weather shocks are crop specific and region specific in nature, therefore, there is a need to strengthen region-specific or crop-specific early warning system to provide farmers timely information on weather conditions, so that, they become better-prepared to choose crops and other agronomic practices in anticipation of a shock.

6. **Promoting Climate-resilient Crops and Mix-cropping:**

   In order to minimize the adverse effects of weather shocks, the government should promote climate-resilient crops not only in Punjab but in India also. Similarly mix-cropping is also need of the hours to reduce the losses in productivity from extreme weather shocks.

7. **Crop Diversification as a Primary Tool for Climate Adaptation:**

   Since coefficient of CEI has been found positive and significant in adaptation analysis in this study, therefore it is suggested that in the formulation of agricultural policy, crop diversification must be given importance as primary tool against climatic shocks.

8. **Practice Training Oriented:**

   The availability of input sources are region-specific; hence there is a need of practical guidance and necessary (soil quality, water requirement etc.) information to inefficient tehsils in selecting the appropriate combination of inputs at given input prices so that they could develop and adopt better allocation of resources and other practices in production process. Therefore, it is suggested to conduct regular practice oriented training programme to the farmers of inefficient tehsils so that farmers can utilise proper technology which would improve their assets quality; and ultimately enhance their technical efficiency and productivity level.

## 6.4 Limitation and Directions for Future Research

Though the present research entitled '*An Empirical Analysis of Determinants of Crop Diversification in Punjab.'* has been able to accomplished significant results, there are some issues that need to be addressed in future research and limitation of the study.

1) In this study, entire analysis is carried out using secondary data at farm level. Further studies can be accompanied using primary data which may drive the results that would have the scope of capturing the true experiences of farmers under study.
2) This study is mainly focused on static modelling approaches to see the impact of crop diversification on crop productivity in the presence of weather shocks, but do not emphasize on the dynamic relationships that exist in the production process. Farmers' current year decisions on the choice of crop pattern and resources use are influenced not only by the anticipated weather conditions but also by their past experiences. Therefore, for further analysis it can be estimate the dynamic impact of the variables.
3) This study is analyzed the impact of weather shocks on crop productivity in aggregate and district level, further it can be seen on disaggregate level such as household level or farmers size of land holding.
4) In this study only estimated the linear impact of the variables on crop productivity, further it can be seen the non-linear impacts of the variables by adding square term in the analysis.

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# *Appendices*

# Appendix A

# Appendix of Chapter 3

**Figure A1:** Cropping pattern in Punjab, 1960-61

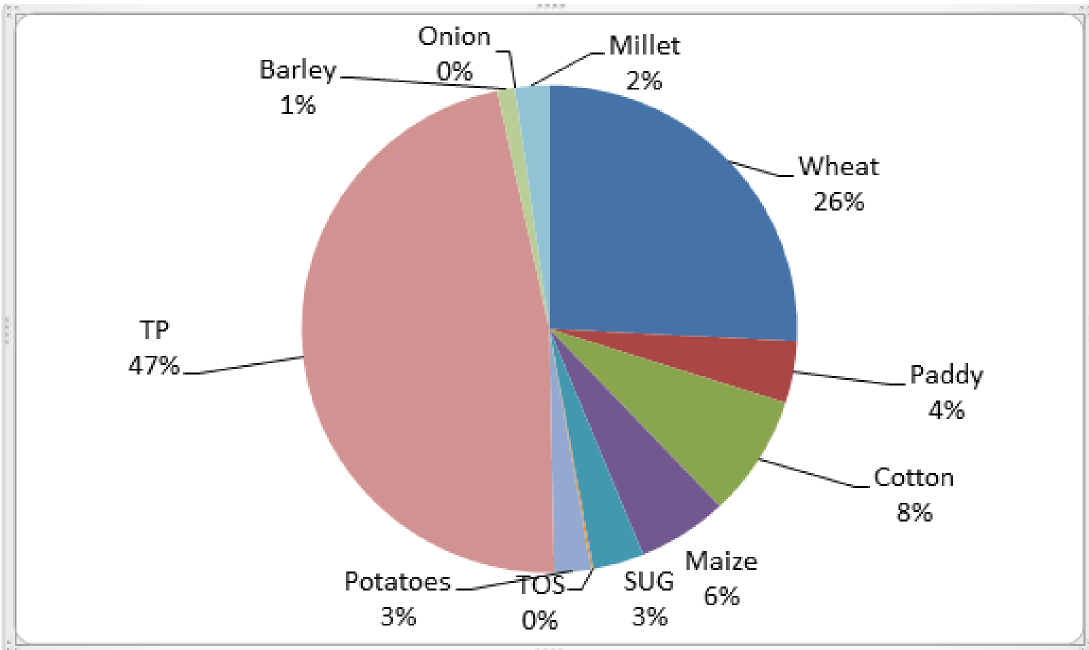



**Figure A2:** Cropping pattern in Punjab, 2017-18

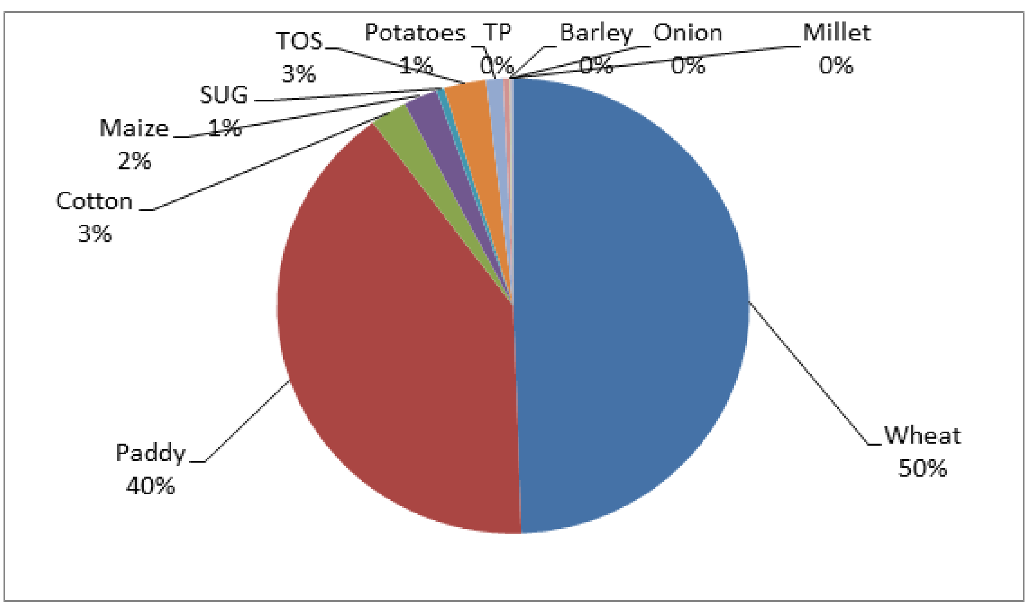


**Table A1:** Proportion of production each crop to total cropped area in Punjab (000' tonne).

| Years | Wheat | Rice | Cotton | Maize | TOS | Potato | Sugarcane | TP | Barley | Onion | Millets |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1960-61 | 32.43 | 4.39 | 2.23 | 6.91 | 2.25 | 2.42 | 9.07 | 38.20 | 0.97 | 0.03 | 1.10 |
| 1965-66 | 42.20 | 6.45 | 2.87 | 14.16 | 4.50 | 5.18 | 12.71 | 8.59 | 1.52 | 0.06 | 1.76 |
| 1970-71 | 60.99 | 7.92 | 2.07 | 10.21 | 2.75 | 2.56 | 6.25 | 3.66 | 0.68 | 0.04 | 2.88 |
| 1975-76 | 55.68 | 13.92 | 1.86 | 8.14 | 2.53 | 4.78 | 5.90 | 3.87 | 1.46 | 0.04 | 1.82 |
| 1980-81 | 57.02 | 23.94 | 1.60 | 4.49 | 1.39 | 5.57 | 2.91 | 1.49 | 0.80 | 0.12 | 0.66 |
| 1985-86 | 58.97 | 29.24 | 1.54 | 2.21 | 1.06 | 2.29 | 2.71 | 1.09 | 0.59 | 0.15 | 0.14 |
| 1990-91 | 57.99 | 31.18 | 1.91 | 1.60 | 0.53 | 2.38 | 2.87 | 0.77 | 0.49 | 0.23 | 0.06 |
| 1995-96 | 56.24 | 30.41 | 1.47 | 1.38 | 1.38 | 3.77 | 4.00 | 0.64 | 0.53 | 0.14 | 0.04 |
| 2000-01 | 56.30 | 33.14 | 0.80 | 1.67 | 0.32 | 4.30 | 2.81 | 0.16 | 0.39 | 0.09 | 0.02 |
| 2005-06 | 52.61 | 37.00 | 1.65 | 1.46 | 0.33 | 4.23 | 1.76 | 0.10 | 0.23 | 0.61 | 0.02 |
| 2010-11 | 53.94 | 35.49 | 1.28 | 1.61 | 0.23 | 5.27 | 1.37 | 0.06 | 0.14 | 0.60 | 0.01 |
| 2015-16 | 50.57 | 37.18 | 0.55 | 1.33 | 0.18 | 7.34 | 2.08 | 0.04 | 0.11 | 0.61 | 0.002 |
| 2017-18 | 51.11 | 35.55 | 0.94 | 1.91 | 0.18 | 7.75 | 1.87 | -0.04 | 0.09 | 0.64 | 0.002 |

*Source:* Author's Calculation by using data from Directorate of Economics and Statistics.

**Table A2:** Productivity of each crop in Punjab (kg/hectare)

| Years | Wheat | Rice | Cotton | Maize | TOS | Potatoes | Sugarcane | TP | Barley | Onion | Millets |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1960-61 | 1244 | 1032 | 269 | 1135 | 654 | 16949 | 36 | 788 | 811 | 12193 | 480 |
| 1965-66 | 1544 | 1000 | 302 | 1670 | 936 | 16123 | 35 | 605 | 1030 | 12493 | 513 |
| 1970-71 | 2237 | 1765 | 368 | 1552 | 790 | 12781 | 41 | 747 | 1007 | 12793 | 1173 |
| 1975-76 | 2373 | 2552 | 347 | 1465 | 833 | 18684 | 54 | 917 | 1265 | 13093 | 1046 |
| 1980-81 | 2730 | 2736 | 316 | 1601 | 755 | 19288 | 55 | 592 | 1662 | 14000 | 1254 |
| 1985-86 | 3531 | 3179 | 507 | 1585 | 959 | 10224 | 65 | 907 | 2197 | 25091 | 871 |
| 1990-91 | 3715 | 3229 | 607 | 1787 | 958 | 19512 | 59 | 734 | 2757 | 27222 | 1091 |
| 1995-96 | 3884 | 3132 | 441 | 1795 | 1214 | 18013 | 65 | 806 | 3132 | 19938 | 1000 |
| 2000-01 | 4563 | 3506 | 366 | 2794 | 1697 | 19563 | 64 | 740 | 3406 | 20920 | 1000 |
| 2005-06 | 4179 | 3858 | 750 | 2723 | 1698 | 16311 | 58 | 804 | 3316 | 22237 | 1000 |
| 2010-11 | 4693 | 3828 | 698 | 3692 | 1336 | 24988 | 60 | 910 | 3667 | 22055 | 1000 |
| 2014-15 | 4294 | 3838 | 376 | 3651 | 1265 | 2510 | 75 | 1265 | 3582 | 22500 | 1000 |
| 2017-18 | 4700 | 4000 | 750 | 3697 | 1454 | 2510 | 89 | 1454 | 2827 | 22905 | 1000 |

*Source:* Author's Calculation by using data from Directorate of Economics and Statistics.

# Appendix B

# Appendix of Chapter 4

**Table B1:** Panel unit root test

| Variables | Statistics (Modified inverse chi2 Pm) |
|---|---|
| Ln Agricultural Productivity | 5.86*** |
| d_day | 14.78*** |
| CEI | 4.32*** |
| FERT | 4.22*** |
| SIRR | 1.38*** |

Note: This table presents the results of panel unit root test that we have performed to check stationary for variables. Whereas, *** p<0.01, ** p<0.05, * p<0.1 represent the significance level at 1%, 5%, and 10% respectively. Note: null hypothesis of unit root is rejected

**Table B2:** Modified Wald test for heteroscedasticity

| Variables | Log linear |
|---|---|
| Log of Agricultural Productivity $\chi^2$ (11) | 4.37 |

Note: This table shows the results of the Modified Wald test. We find chi2 statistics to be statistically significant at the 1% level, suggesting the presence of heteroscedasticity in the model. Whereas, *** p<0.01, ** p<0.05, * p<0.1 represent the significance level at 1%, 5%, and 10% respectively. To resolve heteroscedasticity issue we robust the districts.

**Table B3:** Hausman test statistics (Fixed effects vs. Random effects)

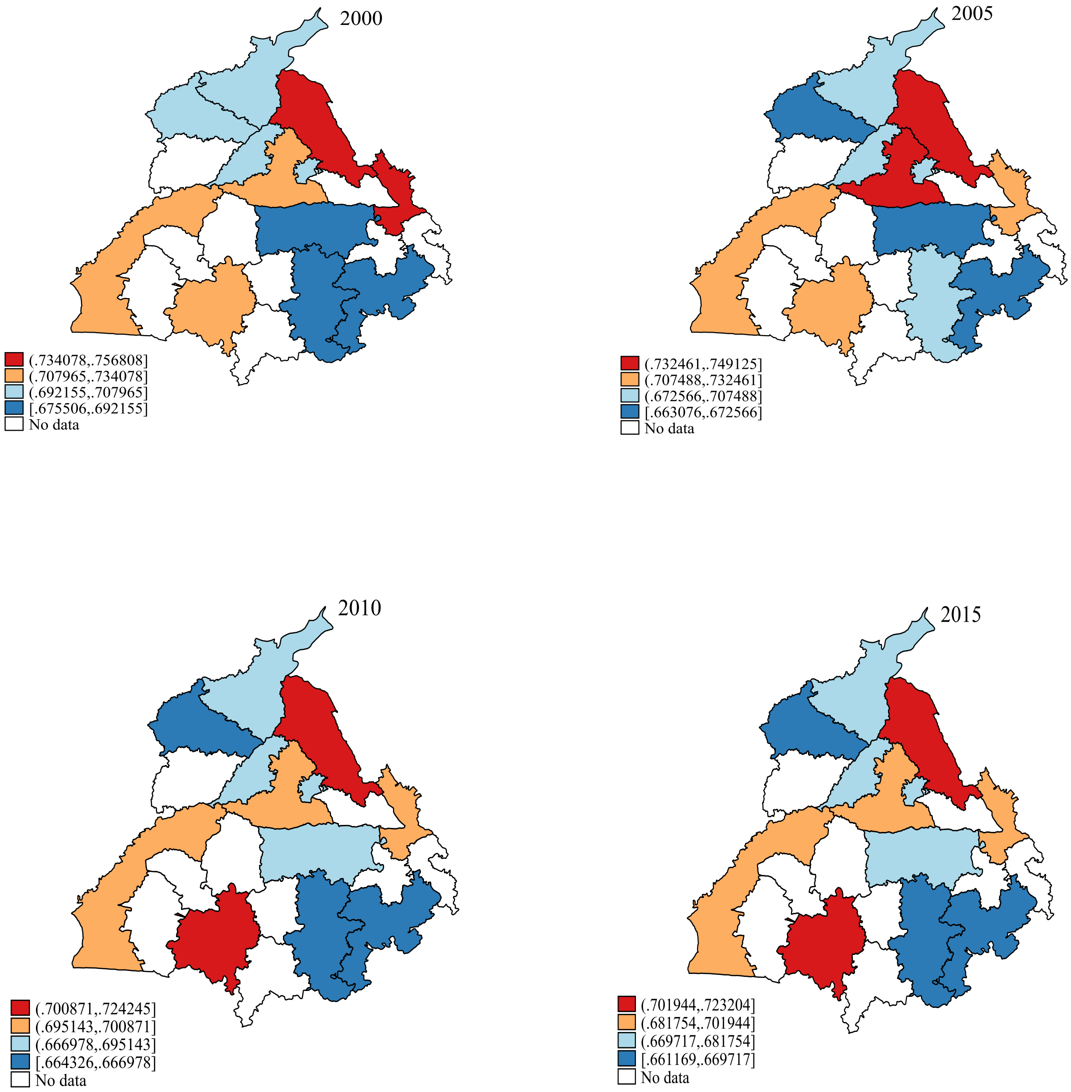
| Variables | Log linear |
|---|---|
| Log of Agricultural Productivity $\chi^2$ (10) | 34.93*** |

Note: This table shows the results of the Hausman test that we have performed to select the appropriate model between fixed and random effects model for our analysis purposes. The results depict that the Hausman test favours the fixed effects model over the random effects model. Whereas, *** p<0.01, ** p<0.05, * p<0.1 represent the significance level at 1%, 5%, and 10% respectively.

**Table B4:** Summary statistic of climate variables

| Statistics | Rainfall arrival day | Total rainfall in MJJA (mm) | Rainy days in MJJA |
|---|---|---|---|
| Minimum | 139 | 85 | 30 |
| Mean | 192 | 596 | 73 |
| Maximum | 243 | 1711 | 117 |
| Standard deviation | 18 | 285 | 15 |

**Figure B1:** Variation in crop diversification




Note: This figure presents the diversification index pattern across the districts in Punjab.

**Figure B2:** Extent of crop diversification

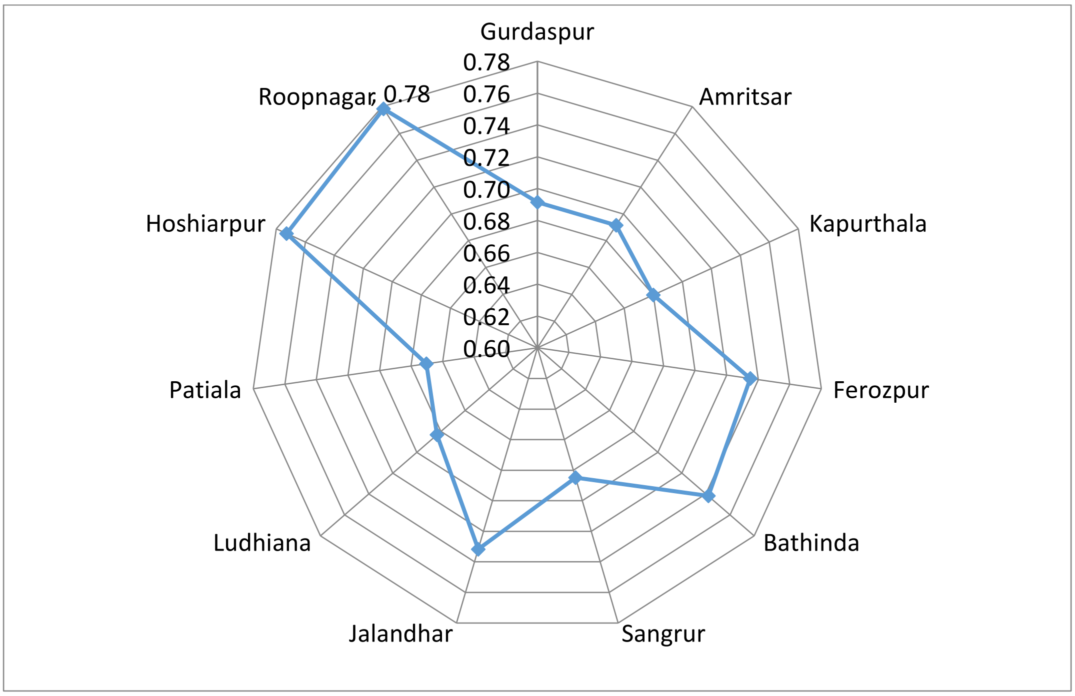
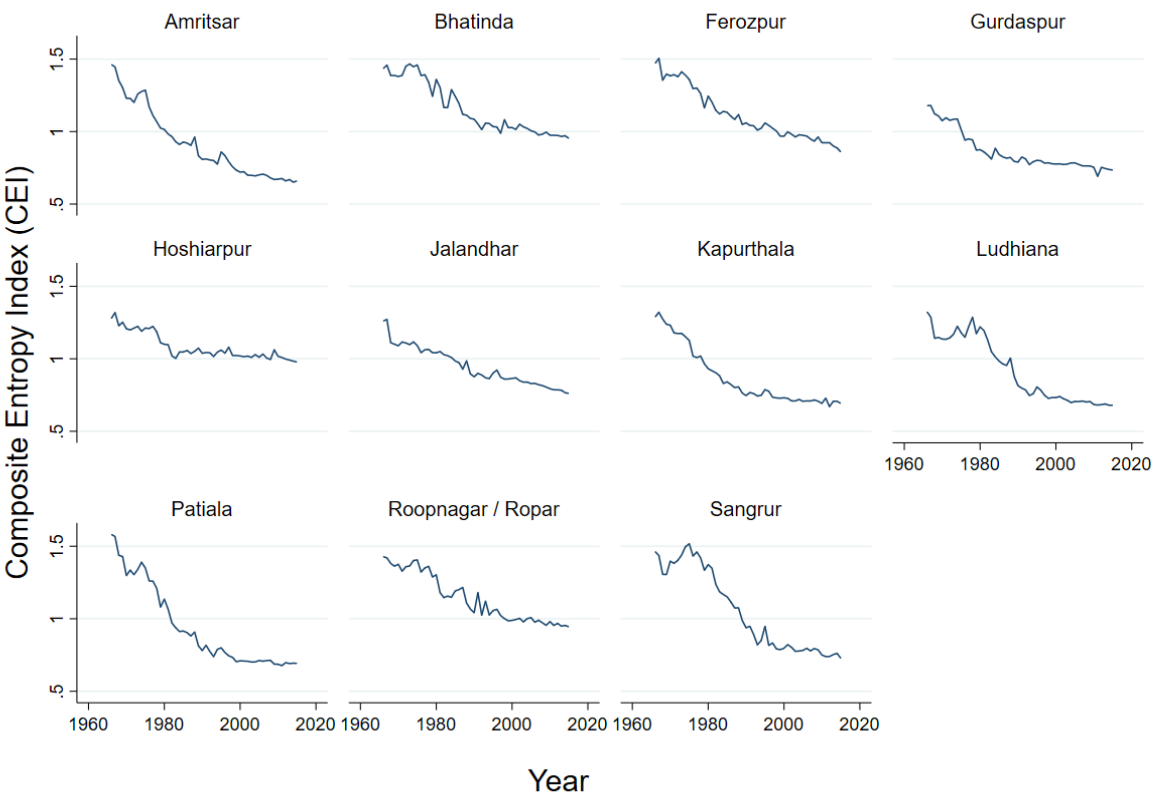



**Figure B3:** Changes pattern of diversification index across districts in Punjab




Note: This figure presents the diversification index pattern across the districts in Punjab.

# Appendix C

# Appendix of Chapter 5

**Table C1:** Input and output variables and description

| Variables | Description |
|---|---|
| Output | |
| Production and by-product | Output of the crops is measured in terms of quintals per hectare including by-products. The by-products are converted into quintals of crops by dividing total value of by-products by crop price |
| Inputs | |
| Human labour | Human labour is combination of family labour per hectare hours plus attached labour per hectare hours plus casual labour per hectare hours for both selected crops. |
| Machine | Machine includes hired machine per hectare hours plus own machine per hectare hours for both wheat and paddy. |
| Seeds | For wheat seeds consist seed quantity kilogram per hectare, while unavailability of seed quantity data for paddy we have taken seed value (Rs) per hectare. |
| Fertilizer | Fertilizer consist three groups nitrogen (N) kilogram per hectare plus phosphors (P) kilogram per hectare plus potassium (K) kilogram per hectare plus others fertilizers. |
| Irrigation | Irrigation includes own irrigation machine per hectare hours plus hired irrigation machine per hectare hours. |

**Table C2:** Return to scale summary statistics tehsils

| Scale classification | Wheat | | Paddy | |
|---|---|---|---|---|
| | Number | Percent | Number | Percent |
| CRS | 7 | 23.33 | 7 | 24.13 |
| IRS | 23 | 73.33 | 22 | 75.86 |
| DRS | 1 | 3.33 | 1 | 3.44 |
| Total | 30 | 100 | 29 | 100 |

Note: CRS, constant returns to scale; IRS, increasing returns to scale; DRS, decreasing returns to scale

**Table C3:** Descriptive statistics of wheat

| Statistics | All Tehsil | Efficient Tehsil | Inefficient Tehsil | PTE | SE |
|---|---|---|---|---|---|
| Tehsil(N) | 30 | 7 | 23 | 30 | 30 |
| AOTE | 0.939 | 1.000 | 0.920 | 0.983 | 0.955 |
| SD | 0.062 | 0.000 | 0.060 | 0.026 | 0.059 |
| Minimum | 0.752 | 1.000 | 0.750 | 0.888 | 0.752 |
| Q1 | 0.918 | 1.000 | 0.890 | 0.975 | 0.929 |
| Median | 0.944 | 1.000 | 0.930 | 1.000 | 0.979 |
| Q3 | 0.993 | 1.000 | 0.971 | 1.000 | 0.999 |
| Maximum | 1.000 | 1.000 | 0.991 | 1.000 | 1.000 |
| AOTIE | 0.060 | 0.000 | 0.079 | 0.0163 | 0.045 |
| Interval | (0.876,1.002) | (1.000,1.000) | (0.860,0.981) | (0.957,1.009) | (0.896,1.014) |

Notes: AOTE= Average overall technical efficiency; SD= Standard Deviation; Q1 = First Quartile; Q = Third Quartile; AOTIE =Average overall technical inefficiency=(1-AOTE); and Interval=(AOTESD; AOTE+SD)

**Table C4:** Descriptive statistics of paddy

| Statistics | All Tehsil | Efficient Tehsil | Inefficient Tehsil | PTE | SE |
|---|---|---|---|---|---|
| Tehsil(N) | 29 | 7 | 22 | 29 | 29 |
| AOTE | 0.836 | 1.000 | 0.784 | 0.959 | 0.868 |
| SD | 0.153 | 0.000 | 0.139 | 0.056 | 0.130 |
| Minimum | 0.516 | 1.000 | 0.516 | 0.818 | 0.576 |
| Q1 | 0.683 | 1.000 | 0.679 | 0.933 | 0.754 |
| Median | 0.881 | 1.000 | 0.735 | 0.991 | 0.909 |
| Q3 | 0.992 | 1.000 | 0.948 | 1.000 | 0.995 |
| Maximum | 1.000 | 1.000 | 0.985 | 1.000 | 1.000 |
| AOTIE | 0.163 | 0.000 | 0.215 | 0.040 | 0.131 |
| Interval | (0.683,0.989) | (1.000,1.000) | (0.644,0.924) | (0.902,1.015) | (0.738,0.998) |

Notes: AOTE= Average overall technical efficiency; SD= Standard Deviation; Q1 = First Quartile; Q = Third Quartile; AOTIE =Average overall technical inefficiency=(1-AOTE); and Interval=(AOTESD; AOTE+SD)

**Table C5:** Discrimination of efficient tehsil (wheat)

| Highly Robust Tehsils | Lowest Robust Tehsils | Marginally Robust Tehsils |
|---|---|---|
| Talwandi Sabo (18) | Jalandhar (8) | Malout (3) |
| Payal(17) | Budhlada (6) | Sultanpurlodhi (3) |
| | Hoshiarpur 1(5) | |

Note: The figures in the parenthesis are frequency count.

**Table C6:** Discrimination of efficient tehsil (paddy)

| Highly Robust Tehsils | Lowest Robust Tehsils | Marginally Robust Tehsils |
|---|---|---|
| Sangrur (12) | Malerkotla (8) | Moga(3) |
| | Guruharsahai (8) | Fazilka (1) |
| | Jaladhar (7) | |
| | Mansa (6) | |

Note: The figures in the parenthesis are frequency count.

**Table C7:** Estimated rank from Equation (5.2) of wheat

| Tehsil Code | Efficient Tehsils | Super efficiency score |
|---|---|---|
| T26 | Talwandi Sabo | 2.6897 |
| T6 | Hoshiarpur 1 | 1.3028 |
| T20 | Jalandhar | 1.1822 |
| T24 | Budhlada | 1.1404 |
| T28 | Malout | 1.0614 |
| T16 | Sultanpurlodhi | 1.0610 |
| T17 | Payal | 1.0436 |

**Table C8:** Estimated rank from Equation (5.2) of paddy

| Tehsil Code | Efficient Tehsils | Super efficiency score |
|---|---|---|
| T19 | Sangrur | 1.1603 |
| T23 | Mansa | 1.1168 |
| T21 | Malerkotla | 1.0792 |
| T12 | Guruharsahai | 1.0609 |
| T29 | Fazilka | 1.0558 |
| T20 | Jalandhar | 1.0371 |
| T13 | Moga | 1.0034 |

**Table C9:** Descriptive summary of different efficiencies

| Efficiencies | Wheat | | | | | Paddy | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Obs | Mean | SD | Min | Max | Obs | Mean | SD | Min | Max |
| TE | 30 | 0.94 | 0.06 | 0.75 | 1 | 29 | 0.81 | 0.15 | 0.53 | 1 |
| AE | 30 | 0.77 | 0.12 | 0.38 | 1 | 29 | 0.85 | 0.11 | 0.54 | 1 |
| CE | 30 | 0.73 | 0.12 | 0.34 | 1 | 29 | 0.69 | 0.17 | 0.32 | 1 |
| SE | 30 | 0.95 | 0.06 | 0.75 | 1 | 29 | 0.87 | 0.13 | 0.58 | 1 |