DELINEATION OF THERMAL REQUIREMENTS OF RICE (*Oryza sativa* L.) STAGGERED IN DIFFERENT TRANSPLANTING WINDOWS AND THEIR VALIDATION

Thesis

Submitted to the Punjab Agricultural University in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
in
AGRICULTURAL METEOROLOGY
(Minor Subject: Agronomy)

By

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CERTIFICATE - I

This is to certify that the thesis entitled, **"Delineation of thermal requirements of rice (*Oryza sativa* L.) staggered in different transplanting windows and their validation "** submitted for the degree of **Master of Science** in the subject of **Agricultural Meteorology** (Minor subject: **Agronomy**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Ms. Upasna Manhas (L-2018-A-31-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE – II

This is to certify that the thesis entitled, "**Delineation of thermal requirements of rice (*Oryza sativa* L.) staggered in different transplanting windows and their validation**" submitted by **Ms. Upasna Manhas** (Admn. No. **L-2018-A-31-M**) to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.Sc.** in the subject of **Agricultural Meteorology** (Minor subject: **Agronomy**) has been approved by the Student's Advisory Committee along with External Examiner after an oral examination on the same.

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ABSTRACT

The present study entitled "Delineation of thermal requirements of rice (*Oryza sativa* L.) staggered in different transplanting windows and their validation" was carried out during *Kharif* season 2019-20 at research farm of Department of Climate Change and Agricultural Meteorology. The experiment was conducted with three rice varieties (PR115, PR118 and PR124) under three dates of transplanting dates (13th June, 21st June and 29th June) in Randomized block design with three replications. The results of phenological studies revealed that the crop transplanted early (13th June) took more number of days (137) to reach physiological maturity and accumulated more heat units as compared to delayed transplanting (21st June and 29th June). Historical analysis of accumulated growing degree days (AGDD) of rice in Punjab from 1990-2019 under transplanting window I, II and III showed that there was increasing trend of AGDD in all the districts except the Ludhiana and Bathinda where no such prominent increasing trend was found. Among all the districts, the highest rate (23.85°C day year^{-1}**)** of AGDD increased was in S.B.S. Nagar. The lowest rate (2.29°C day year^{-1}**)** of increase was in Ludhiana. In the whole state, to complete different phenological stages during different pentads under three transplanting windows, the highest heat units were accumulated by the crop at Muktsar during period P1 (1990-1994) to P6 (2015-2019). The lowest heat units were accumulated by S.B.S. Nagar from pentad P1 (1990-1994) to P4 (2005-2009) and by Jalandhar in P5 (2010-2014) and by Ludhiana in P6 (2015-2019). Trend analysis of heat use efficiency (HUE) of rice from 1990-2018 showed that under three transplanting windows the highest rate of increase in HUE was in Ludhiana. The decreasing rate was found in Rupnagar, S.B.S. Nagar and Amritsar under transplanting window I and in Rupnagar and Amritsar under transplanting window II and III. Spatio-temporal interpolation of variability of thermal requirements of rice in different districts of Punjab had been demarcated using geospatial technology. The results showed that growing degree days accumulation had increased in all the districts of Punjab from 1990-2019. Maximum accumulation of heat units is in first transplanting window followed by second and then in third. Results of validation of historical thermal requirements with actual experimental data under staggered transplanting were, the most positive deviation at maximum tillering, anthesis and physiological maturity occurred in North-east districts (S.B.S Nagar and Hoshiarpur) and most negative deviation at Muktsar during different Pentads. Study of predicted temporal variability in thermal requirements of rice under three transplanting windows showed that most positive deviation at tillering, anthesis and physiological maturity during different pentads occurred at Muktsar during F6 (2045-2049) and lowest deviation at Hoshiarpur during F1 pentad. So the present study may help in the deciding the right time of transplanting and match phenology of crop in specific environment to achieve higher yield.

Keywords: Rice, Dates of transplanting, Phenology, Accumulated growing degree days (AGDD), Spatio-temporal variation, Heat use efficiency (HUE), Geo-spatial technology

Signature of Major Advisor **Signature of the Student**

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ਸ਼ਾਰ ਅੰਸ਼

ਮੌਜੂਦਾ ਅਧਿਐਨ "ਵੱਖ-ਵੱਖ ਟ੍ਰਾਂਸਪਲਾਂਟਿੰਗ ਵੰਡੋਜ ਵਿੱਚ ਝੋਨੇ (*ਓਰਾਈਜਾ ਸ਼ਟਾਵੀਆ* ਐਲ.) ਦੀਆਂ ਤਾਪਮਾਨ ਜਰੂਰਤਾਂ ਦਾ ਵਰਣਨ ਅਤੇ ਉਨ੍ਹਾਂ ਦੀ ਪ੍ਰਮਾਣਿਕਤਾ" ਸਿਰਲੇਖ ਅਧੀਨ ਸਾਉਣੀ ਵਿੱਚ ਸਾਲ 2019-20 ਦੌਰਾਨ ਜਲਵਾਯੂ ਪਰਿਵਰਤਨ ਅਤੇ ਖੇਤੀ ਮੌਸਮ ਵਿਭਾਗ ਦੇ ਖੋਜ ਫਾਰਮ ਵਿਖੇ ਕੀਤਾ ਗਿਆ। ਤਜਰਬਾ ਆਰ.ਬੀ.ਡੀ. ਵਿਧੀ ਤਹਿਤ ਝੋਨੇ ਦੀਆਂ ਤਿੰਨ ਕਿਸਮਾਂ (ਪੀ.ਆਰ.115, ਪੀ.ਆਰ.118 ਅਤੇ ਪੀ.ਆਰ.124) ਅਤੇ ਤਿੰਨ ਲੁਆਈ ਦੀਆਂ ਤਰੀਕਾਂ (13 ਜੂਨ, 21 ਜੂਨ ਅਤੇ 29 ਜੂਨ) ਨੂੰ ਮੁੱਖ ਰੱਖ ਕੇ ਤਿੰਨ ਵਾਰ ਦੁਹਰਾਇਆ ਗਿਆ। ਫਿਨੋਲਜੀ ਦੇ ਅਧਿਐਨ ਤੋਂ ਪਤਾ ਲੱਗਿਆ ਕਿ 13 ਜੂਨ ਨੂੰ ਟ੍ਰਾਂਸਪਲਾਂਟ ਕੀਤੇ ਝੋਨੇ ਨੇ ਆਪਣਾ ਜੀਵਨ ਚੱਕਰ ਪੂਰਾ ਕਰਨ ਲਈ ਸਭ ਤੋਂ ਵੱਧ ਦਿਨ ((137)) ਅਤੇ ਸਭ ਤੋਂ ਜਿਆਦਾ GDD ਐਕੂਮੂਲੇਟ ਕੀਤੇ। ਪੰਜਾਬ ਵਿੱਚ 1990-2019 ਤੱਕ ਝੋਨੇ ਦੀਆਂ ਤਿੰਨ ਟ੍ਰਾਂਸਪਲਾਂਟਿੰਗ ਵੰਡੋਜ ਦੇ AGDD ਦੇ ਇਤਿਹਾਸਿਕ ਅੰਕੜਿਆਂ ਦਾ ਮੁੱਲਾਂਕਣ ਕੀਤਾ ਗਿਆ। ਝੋਨੇ ਦੀ AGDD ਵਿੱਚ ਵਾਧੇ ਦਾ ਰੁਝਾਨ ਲੁਧਿਆਣਾ ਅਤੇ ਬਠਿੰਡਾ ਨੂੰ ਛੱਡ ਕੇ ਪੰਜਾਬ ਦੇ ਸਾਰਿਆ ਜਿਲ੍ਹਿਆਂ ਵਿੱਚ ਦਰਜ ਕੀਤਾ ਗਿਆ। ਜਿਲ੍ਹਿਆਂ ਵਿੱਚੋਂ AGDD ਵਿੱਚ ਵਾਧੇ ਦੀ ਸਭ ਤੋਂ ਵੱਧ ਦਰ (23.85°C day year^{-1}) ਸ਼ਹੀਦ ਭਗਤ ਸਿੰਘ ਨਗਰ ਅਤੇ ਸਭ ਤੋਂ ਘੱਟ ਦਰ ਲੁਧਿਆਣਾ (2.29°C day year^{-1}) ਵਿੱਚ ਦਰਜ ਕੀਤੀ ਗਈ। ਮੁਕੱਤਸਰ ਜਿਲ੍ਹੇ ਵਿੱਚ ਫ਼ਸਲ ਨੇ ਆਪਣੀਆਂ ਫਿਨੋਲਜੀਕਲ ਸਟੇਜਾਂ ਨੂੰ ਪੂਰਾ ਕਰਨ ਲਈ P1 (1990-1994) ਤੋਂ P6 (2015-2019) ਪੈਂਟਾਡ ਦੌਰਾਨ ਸਭ ਤੋਂ ਵੱਧ ਤਾਪਮਾਨ ਯੂਨਿਟਾਂ ਦੀ ਵਰਤੋਂ ਕੀਤੀ। ਜਦੋਂਕਿ ਸਭ ਤੋਂ ਘੱਟ ਤਾਪਮਾਨ ਯੂਨਿਟਾਂ ਕ੍ਰਮਵਾਰ ਸ਼ਹੀਦ ਭਗਤ ਸਿੰਘ ਨਗਰ ਵਿੱਚ P1 (1990-1994) ਤੋਂ P4 (2005-2009), ਜਲੰਧਰ ਵਿੱਚ P5 (2010-2014) ਅਤੇ ਲੁਧਿਆਣਾ ਵਿੱਚ P6 (2015-2019) ਦਰਜ ਕੀਤੀ ਗਈ। 1990-2018 ਤੱਕ ਦੇ HUE ਦੇ ਅੰਕੜਿਆਂ ਦਾ ਮੁੱਲਾਂਕਣ ਕੀਤਾ ਗਿਆ। ਝੋਨੇ ਦੀ HUE ਵਿੱਚ ਤਿੰਨ ਟ੍ਰਾਂਸਪਲਾਂਟਿੰਗ ਵੰਡੋਜ ਵਿੱਚ ਵਾਧੇ ਦੀ ਸਭ ਤੋਂ ਵੱਧ ਦਰ ਲੁਧਿਆਣਾ ਵਿੱਚ ਅਤੇ ਟ੍ਰਾਂਸਪਲਾਂਟਿੰਗ ਵੰਡੋ I ਵਿੱਚ ਸਭ ਤੋਂ ਘੱਟ ਦਰ ਰੂਪਨਗਰ, ਸ਼ਹੀਦ ਭਗਤ ਸਿੰਘ ਨਗਰ ਅਤੇ ਅੰਮ੍ਰਿਤਸਰ ਅਤੇ ਟ੍ਰਾਂਸਪਲਾਂਟਿੰਗ ਵੰਡੋ II ਤੇ III ਵਿੱਚ ਰੂਪਨਗਰ ਅਤੇ ਅੰਮ੍ਰਿਤਸਰ ਵਿੱਚ ਦਰਜ ਕੀਤੀ ਗਈ। ਭੂ-ਸਥਾਨਿਕ ਟੇਕਨੋਲਜੀ ਰਾਹੀਂ ਨਕਸ਼ਿਆਂ ਦੀ ਮਦਦ ਨਾਲ ਝੋਨੇ ਦੀਆਂ ਤਾਪਮਾਨ ਜਰੂਰਤਾਂ ਵਿੱਚ ਬਦਲਾਵ ਦਾ ਅਧਿਐਨ ਕੀਤਾ ਗਿਆ। ਅਧਿਐਨ ਤੋਂ ਪਤਾ ਲੱਗਿਆ ਕਿ 1990-2019 ਤੱਕ ਪੰਜਾਬ ਦੇ ਸਾਰਿਆਂ ਜਿਲ੍ਹਿਆਂ ਵਿੱਚ ਝੋਨੇ ਦੇ AGDD ਵਿੱਚ ਵਾਧਾ ਹੋਇਆ ਹੈ। ਇਹ ਵਾਧਾ ਕ੍ਰਮਵਾਰ ਝੋਨੇ ਦੀ ਟ੍ਰਾਂਸਪਲਾਂਟਿੰਗ ਵੰਡੋ I, II ਤੇ III ਵਿੱਚ ਦਰਜ ਕੀਤਾ ਗਿਆ। ਮੌਜੂਦਾ ਤਜਰਬੇ ਦੇ AGDD ਦੇ ਅੰਕੜਿਆਂ ਦੀ ਵਰਤੋ ਇਤਿਹਾਸਿਕ AGDD ਦੇ ਅੰਕੜਿਆਂ ਦੀ ਪ੍ਰਮਾਣਿਕਤਾ ਲਈ ਕੀਤੀ ਗਈ। ਜਿਸ ਤੋਂ ਪਤਾ ਲੱਗਿਆ ਕਿ ਵੱਖ-ਵੱਖ ਪੈਂਟਾਡ ਵਿੱਚ ਝੋਨੇ ਦੀ ਬੂਝਾ ਮਾਰਨ, ਬੂਰ ਪੈਣ ਅਤੇ ਪੱਕਣ ਸਮੇਂ ਦੀ AGDD ਵਿੱਚ ਸਭ ਤੋਂ ਵੱਧ ਬਦਲਾਵ ਉੱਤਰ-ਪੂਰਬੀ ਜਿਲ੍ਹਿਆਂ (ਸ਼ਹੀਦ ਭਗਤ ਸਿੰਘ ਨਗਰ ਤੇ ਹੁਸ਼ਿਆਰਪੁਰ) ਅਤੇ ਸਭ ਤੋਂ ਘੱਟ ਬਦਲਾਵ ਮੁਕੱਤਸਰ ਵਿੱਚ ਦਰਜ ਕੀਤਾ ਗਿਆ। ਭਵਿੱਖ ਵਿੱਚ ਇਹਨਾਂ ਫਿਨੋਲਜੀਕਲ ਸਟੇਜਾਂ ਵਿੱਚ ਸਭ ਤੋਂ ਵੱਧ ਬਦਲਾਵ ਮੁਕੱਤਸਰ ਵਿੱਚ F6(2045-2049) ਅਤੇ ਸਭ ਤੋਂ ਘੱਟ ਬਦਲਾਵ ਹੁਸ਼ਿਆਰਪੁਰ ਵਿੱਚ ਦਰਜ ਕੀਤਾ ਗਿਆ। ਇਸ ਪ੍ਰਕਾਰ ਮੌਜੂਦਾ ਅਧਿਐਨ ਝੋਨੇ ਦਾ ਵੱਧ ਝਾੜ ਲੈਣ ਲਈ ਫ਼ਸਲ ਦੀ ਫਿਨੋਲਜੀ ਦੇ ਅਨੁਸਾਰ ਸਹੀ ਸਮੇਂ ਤੇ ਝੋਨੇ ਦੀ ਲੁਆਈ ਵੱਲ ਇਸ਼ਾਰਾ ਕਰਦਾ ਹੈ।

ਮੁੱਖ ਸ਼ਬਦ: ਝੋਨਾ, ਲੁਆਈ ਦੀ ਤਰੀਕਾਂ, ਫਿਨੋਲਜੀ, ਐਕੂਮੁਲੇਟਡ ਗ੍ਰੋਇੰਗ ਡਿਗਰੀ ਡੇਜ (AGDD), ਸਪੇਸੀਓ-ਟੈਮਪੋਰਲ ਵੇਰੀਏਸ਼ਨ, ਹੀਟ ਯੂਜ ਏਫੇਸ਼ਿਏਨਸ਼ੀ (HUE), ਭੂ-ਸਥਾਨਿਕ ਟੇਕਨੋਲਜੀ

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ

ਵਿੱਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ

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CHAPTER I

INTRODUCTION

Agriculture is the backbone of our country consisting of 70 per cent of rural households and is root of our civilization. About 52 per cent of the total number of jobs in India is provided by the agriculture sector. The contribution of agriculture to the total GDP is around 17 per cent (Arjun 2013). Weather and climate majorly affect the agricultural productivity in any region (Raza *et al* 2018). The main determinant of agricultural production is climate and is regulated by prevailing climatic factors including light intensity, sunshine duration, rainfall, temperature, air pressure, and humidity level across the region. On global scale both, climate change and agriculture are interrelated processes. Climate change through changes in average temperature, rainfall, and climate extremes, changes in carbon dioxide concentration and ground level ozone concentration affects agriculture. The spatio-temporal analyses of temperature in Punjab state, had shown a significant increase in temperature in different regions (Kingra *et al* 2018). The increase of temperature will have detrimental effect on crop productivity through increasing the rate of respiration and decreasing the net photosynthesis, ultimately resulting in reduced crop productivity (Rao *et al* 2015). The climate change has drawn the attention about the climate change effects on agricultural productivity (Kaur 2016). Since 1880 the earth's average surface temperature had increased by 0.85°C (Barros and Field 2014). Study revealed that by the end of 21^{st} century, the temperature will increase further by 1.6-5.8°C (Pachauri and Reisinger 2007). Under the future climate change scenarios, the northern part of Indian sub-continent has been placed under high risk zone of heat stress (Teixeira *et al* 2013).

For more than half of world’s population, Rice is vital staple food crop and source of 21per cent of the total calories intake (Singh *et al* 2017). Rice is cultivated over wide range of latitude and altitudes. In India, rice (*Oryza sativa* L.) cultivation extends from 8 to 35°N latitude and as high as 3000 meters from sea level. It is also grown under all the 3 rice growing environments like uplands, lowlands and midlands. The major climatic factors affecting growth and yield include solar radiation, temperature and rainfall. The rainfall is particularly important in rainfed rice cultivation. When compared to other crops, the water requirement for rice crop is very high. It is often believed that standing water of at least 5 cm depth is needed for rice crop right from transplanting to flowering and grain filling stages (Sahu *et al* 2018). In 2016-17, rice was grown on 431.94 lakh hectares area with 110.15 million tones of production and productivity of 2550 kg/hectares (Directorate of Economics and Statistics, Department of Agriculture and Cooperation, 2016-17). It is a water loving plant with temperature requirement of 20-37.5°C (Package of Practice, 2017-18). By 2050, the total population of world will become 233.2 million as per the current rate of population growth so, in order to feed this population the estimated demand of rice will be 2000 million metric tons by 2030 (FAO 2002). Changing climate sets a big challenge to achieve this goal of food demand, characterized by current global warming trends (Fischer *et al* 2005).

Variability in weather is major factor for the inter-annual variability of crop growth and yield in all the environments. In order to study the crop responses to ambient air temperature cardinal temperatures are considered which include optimum temperature (CTopt), maximum temperature (CTmax) and minimum temperature (CTmin) (Wang *et al* 2014). The increasing atmospheric temperature causes damaging effects on development, yield and quality of the rice crop by impacting its yield, physiology and phenology (Singh 2001 and Sheehy *et al* 2005). International Food Policy Research Institute (IFPRI) report on 'Climate Change: Impact on Agriculture and Costs of Adaptation' showed that the yield losses in rice due to increase in temperature will be between 10 and 15 per cent by 2050 (Kaur 2016). As projected by global circulation models, the temperature increase of 1.1 to 6.4°C (IPCC 2007) will reduce the duration of rice ranged from 9 to 14 days at the end of the century (Ramaraj *et al* 2013).). Due to global warming, temperature has a profound impact on rice crop phenology (Raza *et al* 2018). Environmental conditions when cool led to delay in achieving the maturity stage while high temperature tend towards earlier completion of the plant development stages. So a crop that is sown at same time in large region is not ready to harvest at the expected time. During the growth time of rice temperature increment of 4°C will cause five to six days early maturation in both wet and dry seasons (Raza *et al* 2018).

Punjab is often called as India's bread basket or 'granary of India'. In Punjab this crop is grown during *kharif* season on area of 31.03 lakh hectares with total production of 191.36 lakh tonnes (Anonymous 2020). About 82 per cent of the land is under agriculture. There is increase in temperature from north-east to south-western region of Punjab. No significant temporal variability trend was observed in maximum temperature but there was significant increase in minimum temperature (@ 0.05°C year) during both *rabi* and *kharif* seasons in different zones of Punjab. This alarming situation demand for analyses of the spatio-temporal variability in climatic patterns at regional scale in order to adopt mitigation strategies on regional basis. (Kingra *et al* 2018). Under Punjab conditions, increase in temperature of 1°C will decrease the rice yield by 3 per cent (Hundal and Kaur 2007)

Various meteorological variables like rainfall, temperature etc. affect rice (Ji *et al* 2007).The thermal responses of different crops act as independent variable for depicting the plant development. Plants require definite temperature for attainment of certain phenological stages. Thermo and photo period is influenced by shifting of the transplanting dates. So study of these effects may help in the deciding the right time of transplanting and match phenology of crop in specific environment to achieve higher yield. In this approach temperature based agrometeorological indices such as Growing degree days (GDD), Heliothermal units (HTU) are quite useful in predicting the growth and yield of crops (Sreenivas *et al* 2010) The estimation of occurrence of various phenological events during the crop growth period in relation to temperature can be done by computing accumulated growing degree days (Gouri *et al* 2005). Thus, generating the information regarding phenological development and impact of weather parameters on rice as well as development is necessary for the yield prediction models for necessary refinement of production technologies in future. (Banerjee *et al* 2018)

Growing degree days (GDD) is a simple temperature-based index of biological development (Hassan *et al* 2007) based on the concept that there is linear relationship between right time for attainment of certain phenological stages and temperature ranging between mean temperature and base temperature. The growing degree days (GDD), photothermal unit (PTU), heliothermal unit (HTU) and phenothermal index (PTI) are some simple tools to find out the relationship between plant growth, temperature, bright sunshine hours and day length. Under field conditions influence of temperature development and yield of crop plants is studied through accumulated heat unit system as plants have a distinct temperature requirement prior the attainment of certain phenological stage. The knowledge of heat units predict the different developmental stages as well as harvest date of crop. Heat units in terms of dry matter is known as Heat use efficiency (HUE) which depends on genetic factors, crop type and sowing time (Rao *et al,* 2015)

There is good interaction of rice with the existing environment. Under changing climatic scenario for getting full potential performance of rice under given agroclimatic conditions, the choice of correct variety and right time of transplanting play a deciding role (Singh *et al* 2012). Studies had showed that if there is delay of 20 days in transplanting, it will lead to 8 days delay in flowering (Joseph 1991) or up to 13 days (Murty and Sahu 1979).

The long-term planning for the sustainable use of resources under future climate change can be made by spatial interpolation of climate characterization (Kingra 2016). By the spatial interpolation, maps of temperature based agro-meteorological indices are generated by the use of data from the meteorological stations, remote sensing techniques and MODIS land surface temperature (LST) (Zhang *et al* 2013). This will be helpful for calculation of thermal requirements of rice in different regions of Punjab.

Although the Punjab state is characterized with phenomenal increase in food grain production due to Green Revolution but the sustainability of natural resources has been endangered. In view of increasing temperature, there will be shortening of rice growing period, ultimately leading to decrease in its productivity. Thus, the fluctuation in rice production in Punjab can significantly influence the grain distribution policies, national food reserves and price regulations as state is a bread basket of India contributing 10.02 per cent to all India foodgrain production (Directorate of Economics and Statistics, Department of

Agriculture and Cooperation, 2016-17). In order to accurate yield estimations at regional level, there is need to evaluate the different thermal requirements of rice crop grown in different transplanting windows for harvesting the maximum yield potential of crop along with sustainability of natural resources and framing future suitable policies and their implementation to cope up with climate change. Due to differential behavior of rice cultivars, the present study was carried out to study the phenological behavior, heat unit requirements and heat use efficiency of rice under different dates of transplanting. Under field experiment the growing degree days of rice crop staggered under different dates of transplanting was studied. Further the contributions of temperature variations to state-level rice yields was assessed for the historical period (1990-2019). Under the RCP8.5 scenario the future heat unit requirement of rice was predicted from the time 2020-2049 pentadwise in the different districts of Punjab.

The present study entitled **"**Delineation of thermal requirements of rice (*Oryza sativa* L.) staggered in different transplanting windows and their validation**"** was undertaken to accomplish the following objectives:

a) To study the spatio-temporal variations of thermal requirements of rice in Punjab.
b) To validate the thermal requirement with actual experimental data under staggered planting.
c) To study the impact of climate change on future thermal requirements of rice.

CHAPTER-II

REVIEW OF LITERATURE

A brief series of the studies conducted at the national and international level relevant to the present study entitled, **"**Delineation of thermal requirements of rice (*Oryza sativa* L.) staggered in different transplanting windows and their validation **"** has been reviewed and presented below:

2.1 Effect of dates of transplanting on phenology, heat units and yield of rice

2.2 Effect of changing climate on phenology, heat units and yield of rice

2.3 Spatio-temporal variability in thermal requirement of rice

2.1 Effect of dates of transplanting on phenology, heat units and yield of rice

Mandal *et al* (2003) conducted a study on thermal time indices and yield correlations for hybrid rice in terai region of West Bengal. The crop was transplanted on 10^{th} June, 25^{th} June and 10^{th} July. The study indicated that GDD accumulation goes on increasing from transplanting to first leaf emergence and fourth leaf emergence to flowering. Comparing the dates of transplanting, 10^{th} June crop accumulated more GDD than 10^{th} July crop mainly due to lower GDD accumulation during ripening period. Grain yield increased with delay in transplanting for each cultivar. This was due to the fact that the late transplanted crop experienced the low temperature with more bright sunshine hours during ripening phase. Correlations studies showed that during ripening period (flowering to maturity) bright sunshine hours (BSH) have significant positive and growing degree days (GDD) have significantly negative (non significant in most of the cases) on grain yield. GDD, HTU, PTU were positively correlated with grain yield.

Sreenivas *et al* (2010) conducted an experiment on agrometeorological indices in relation to phenology of aerobic rice. The treatments included four different dates of transplanting viz., 16^{th} June, 26^{th} June, 7^{th} July and 18^{th} July and two varieties, Jagtiala Sannalu and Polasa Prabha. Jagtiala Sannalu accumulated mean growing degree days of 2017+55 and heliothermal units of 11526+817 from emergence to physiological maturity with coefficient of variation of 3 per cent and 7 per cent, respectively. Similarly, Polasa Prabha accumulated 2102+33 heat units and 12031+716 heliothermal units for same phenological phase with coefficient of variation of 2 per cent and 6 per cent, respectively. Heat use efficiency was also higher for June 16^{th} transplanted crop. From the experiment it was concluded that with the help of AGDD and HTU, physiological maturity can be predicted which account for 84 per cent and 86 per cent variability in both the cultivars. Correlation studies indicated that in Jagtiala Sannalu there exists significant relationship between calendar days and AGDD and HTU from emergence to panicle initiation and emergence to physiological maturity. Whereas, in Polasa Prabha significant relationship exists between calendar days and AGDD in all the growth phases and between calendar days and HTU from emergence to panicle initiation and emergence to physiological maturity. Regression equations developed indicated that phenology can be predicted using AGDD and HTU in both short (Jagtiala Sannalu) and medium (Polasa Prabha) duration varieties.

Sharma *et al* (2011) conducted an experiment at the Research Farm of Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, to study the effect of transplanting time on phenology, growing degree days and yield in rice crop (*Oryza sativa* L.). Two genotypes of rice (PR 116 and PAU 201) were transplanted under two sowing environments (15 June and 30 June). Both the varieties, PR 116 and PAU 201 utilized 2957 and 2942°C day, respectively under 15 June transplanted crop as compared to 30 June transplanted crop which utilized 2742 and 2841°C day respectively to complete the physiological maturity.

Brar *et al* (2011) carried out a field experiment at Students' Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana. They studied the heat unit requirements, phenological behaviour of two cultivars of rice long (PR 118) and medium (PAU 201) under different dates of transplanting (June 15, June 25 and July 5). Pooled analysis showed that the crop transplanted on June 15 took 4 and 6 days more to attain 50 % flowering as compared to June 25th and July 5th transplanted crops, respectively. The difference in duration remained 3 and 4 days at maturity among June 15 and June 25 or July 5 transplanted crops. It was concluded that there was 13 and 24 days reduction in total growing cycle and in accumulated growing degree days to the tune of 86 and 200 heat units by 10 and 20 days delay in transplanting date. Results showed that the cultivar PR 118 took more 129 growing degree days to mature than PAU 201. In cultivar PR 118 there was significantly lower grain yield which may be due to inappropriate partitioning of dry matter contributing more to straw yield. Non significant interaction were obtained between genotypes and date of transplanting. At last they concluded that there was 5.4 per cent reduction in grain yield in long duration cultivar PR118 when transplanting was delayed from June 25 to July 5 whereas medium duration cultivar PAU 201 registered almost equal grain yield even under delayed transplanting on July 5.

Islam *et al* (2011) conducted an experiment at Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh on variations in the phenology and degree days of 5 fine rice cultivars under organic and inorganic cultural conditions. The crop under inorganic culture recorded higher growing degree days (GDD) grain yield and heat use efficiency (HUE) than organic culture as inorganic culture supports longer life span of rice cultivars. For attaining different phenological stages every cultivar differ significantly. Results indicated that phenology was significantly influenced by the interaction effect of cultural conditions and cultivars.

Comparing the cultivars in organic as well as inorganic culture, it was concluded that in organic culture all the cultivars showed higher requirement of days for attaining seedling establishment, initial and maximum tillering stages. But from booting to harvesting stage, this requirement of days decreased as compared to inorganic culture. The combined effect of cultural conditions and cultivars on heat unit was significant at all the phenological stages of rice cultivars. The life duration of all the cultivars were significantly shorter in organic than inorganic culture. The seedling establishment stage took lowest heat unit (GDD) whereas in the successive phenological stages like initial tillering, maximum tillering, booting, heading, anthesis, milking, dough, maturity and harvesting the requirement of heat unit (GDD) increased.

Mohammad *et al* (2013) conducted an experiment on agrometeorological indices in relation to phenology, biomass accumulation and yield of rice genotypes under western plain zone of Uttar Pradesh on 12 rice genotypes. They concluded that cultivar Narendra 359 accumulated higher heat units for panicle initation, 50% flowering and physiological maturity. Heliothermal units (HTU) and Photothermal Units (PTU) were also higher in Narendra 359. Heat use efficiency was higher in Pant Dhan 10 on biomass basis and in PR115 on grain yield basis. Correlation coefficients showed that grain filling duration have positive and significant relation with grain yield whereas, flowering duration have positive and significant correlation with grain and biomass yield. For getting higher yield in the Upper Indo-Gangetic Plain these findings will help in identification and development of rice cultivars with more flowering duration and grain filling duration days. The longer duration cultivars e.g. Narendra 359 and Naveen may be suitable under short photoperiod crop season for getting optimum yield under climate change scenario. The reason for this was that both these cultivars have ability to cumulate higher photoperiod hours at maturity and yielded higher grain yield as sunny days affects the partitioning of total biomass into grain yield through more transportation of the photosynthates towards grain formation.

Kaur *et al* (2014) carried out research at the Research Farm of school of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana. On 15th June, 30th July and 15th July the crop was transplanted. The heat units required to attain different phenological stages increased as transplanting was delayed in both the varieties. To attain different phenological stages, the crop transplanted on 15 June took maximum calendar days, growing degree days, helio-thermal units, photo thermal units and pheno-thermal index till physiological maturity. After 15th June there was significant reduction in agrometeorological indices with delay in transplanting time. Among all the three transplanting dates pheno-thermal index gradually increases from tillering to physiological maturity being the lowest at emergence and highest during grain filling and physiological maturity. The present study indicated that the application of agroclimatic indices provided a scientific basis for determining the effect of temperature, radiation or photoperiod on phenological behaviour of a standing crop.

Khavese *et al* (2015) carried out experiment at Research and Instructional Farm of Indira Gandhi Agricultural University, Raipur (Chhattisgarh), India to examine yield and heat unit requirement of rice with three genotypes as influenced by three sowing dates. The result obtained revealed that crop sown on 10^{th} June recorded higher growing degree days, heat use efficiency, grain yield when compared with 20^{th} June and 30^{th} June sown crop. Moreover, it was concluded that early sowing dates is better than delayed sowing.

Bhat *et al* (2015) conducted a field experiment at Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir Shalimar, Srinagar, Jammu and Kashmir on relation between agrometeorological indices, crop phenology and yield of rice genotypes as influenced by real time nitrogen management during 2012 and 2013. The study was done on two rice genotypes (Jhelum and SR-2). The pooled data showed that SR-2 accumulated more heat units and recorded significantly higher value of yield as compared to Jhelum to attain different phenological stages. This was due to the fact that higher application of nitrogen had increased the number of calendar days and thermal time of the crop which in turn increased GDD and HUE.

Mote *et al* (2015) studied the thermal requirements for attainment of phenophases of rice cultivars under variable weather conditions. The present investigation was carried out at College Farm of Navsari Agricultural University, Navsari (Gujarat), India. To study the requirement of total GDD for three rice cultivars i.e. Jaya, Gurjari and GNR-2 under three dates of transplanting, i.e. 12^{th} July, 27^{th} July and 11^{th}August. Results revealed that the growing degree days (GDD) requirement was higher in Gurjari followed by GNR-2 and Jaya. Among dates of transplanting, higher grain yield was obtained in first date of transplanting and progressive decreased in grain yield was recorded with delay in transplanting, which was mainly due to total GDD decreased during beginning of grain filling to physiological maturity that resulted in reduction in grain yield.

Aggarwal *et al* (2016) carried out research at Punjab Agricultural University, Ludhiana to study the effect of seedling age on heat utilization, radiation interception and productivity of rice. In treatment 3, 4 and 5 weeks-old seedlings. The result showed that 3 weeks old seedlings accumulated highest number of growing degree days (GDD) of 2045°C day upto maturity. The heat use efficiency (HUE) was similar in all transplanted seedlings. The growth and yield attributes get decreased with increasing seedling age from 3 to 5 weeks. The HUE and yield of mechanical transplanted 3, 4 and 5 weeks-old seedlings was found statistically at par. These results enabled the farmer to have wider window to transplant the seedlings mechanically without any significant reduction in grain yield.

Kumar *et al* (2016) carried out an field trail at Chaudhary Charan Singh Haryana

Agricultural University, Regional Research Station, Kaul, India to study the comparative performance of scented/basmati rice (CSR 30) under five different methods of planting viz., machine transplanting under pudlled (M1) and unpuddled conditions (M2), direct seeding under *vattar* conditions (M3), direct seeding under zero tillage (with residue) (M4), conventional practice (nursery raising) (M5). They observed that significantly positive correlation of the growth indices like LAI, CGR, RGR, NAR, LAD, LWR and agrometeorological indices i.e. AGDD, AHTU, APTU, RUE and HUE with yield and yield attributes. During post reproductive phase (90 DAS to maturity) of crop RUE and HUE showed positive correlation with yield and yield attributes, whereas AGDD, AHTU and APTU showed negative correlation with yield and yield attributes. LAI, LAD and CGR were positively correlated with yield and yield attributes during vegetative and active reproductive phase because of greater significance of the leaf area and dry matter accumulation. It may, in fact be a consequence of the relatively longer duration of these growth phases in the crop.

Satish *et al* (2017) conducted experiment at Kerala Agricultural University to study the phenology, and various agrometeorological indices viz. accumulated growing degree days (GDD), helio thermal units (HTU), photo thermal units (PTU), of selected rice cultivars grown under different dates of planting. The treatments included five dates of planting viz. 5th June, 20th June, 5th July, 20th July and 5th August and two rice varieties Jyothi and Kanchana. For both the varieties heat units required to attain different phenological stages decreased with delay in transplanting date to attain different phenological stages but photothermal units showed declining trend towards the delayed date of planting. Among varieties, Jyothi consumed highest GDD, HTU and PTU as compared to other varieties. With delayed in dates of planting lower grain yields was observed in Jyothi and Kanchana. These provide very clear picture of the amount, pattern and efficiency of heat energy consumption at different dates of planting and phenological stages of the crops.

Chauhan *et al* (2017) carried out a field experiment at Chaudhary Charan Singh Haryana Agricultural University, India to study the phenology and various agrometeorological indices *viz.* accumulated growing degree days (GDD), helio thermal units (HTU), photo thermal units (PTU), radiation use efficiency (RUE) and heat use efficiency (HUE) of basmati rice cultivars grown under different dates of transplanting. The rice varieties CSR 30, HB 2, PB 1121 and PB 1509 were transplanted on three dates *viz.* 25th June, 10th July and 25th July. Heat units required to attain different phenological stages decreased in all the varieties with every delay in transplanting date. The crop transplanted on 25th June took maximum calendar days, growing degree days, helio thermal units and photo thermal units, to attain different phenological stages till physiological maturity. Among varieties, CSR 30 consumed highest GDD, HTU and PTU as compared to other varieties. The RUE and HUE for grain production was highest in HB 2 at the time of harvest.

Netam (2017) carried out an experiment at Department of Agrometeorology, Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh) to study the effect of weather parameters on growth and yield of scented rice under different growing environment. The experiment was carried out with regards to the different growing environments. The results revealed that the crop planted on 27th June took longer growing environment, more accumulated growing degree days and heat use efficiency as compared to the growing environments on 12th July and 27th July.

Raju *et al* (2018) conducted an experiment during *rabi* season at Puducherry to study the relationship between weather parameters and yield of rice varieties at different dates of sowing under aerobic condition. Five dates of sowings i.e. September 20th, September 27th, October 4th, October 11th and October 18th and three genotypes namely TRY 1, Improved White Ponni and ADT 39 varieties were chosen. Result showed that as the transplanting dates were delayed there was decreased of Growing Degree Days (GDD) during total lifespan. The accumulated GDD varied from 1507 to 1885.9 with different dates of transplanting. The study clearly demonstrated that the climatic requirement of rice could suitably be matched by altering the transplanting period to get higher yield. It was concluded that during *rabi* season under aerobic condition, the transplanting should not be delayed beyond the 38th meteorological week (September 20th).

Chaudhari *et al* (2018) conducted a field experiment on thermal indices in relation to crop phenology and yield of rice (*Oryza sativa* L.) grown in the south Gujarat region. In this region the crop was raised under irrigated condition. Two varieties differ considerably under different thermal environment with respect to accumulated growing degree days (GDD) from sowing to maturity. Higher GDD, PTUE, HTUE and EDUE was observed under 18 June (D1) in varieties GNR-3 and NAUR-1 and least in crop transplanting under 28 June (D2). The possible reason for this could be that the late sown rice crop that faced high temperature during grain filling and ripening phases which was one of the most important factor which govern the crop phenological development and total biomass production along with efficient conversion of biomass into economic yield.

Sahu *et al* (2018) estimated the GDD (growing degree days) under different phenophase of different rice genotypes under SRI and tradition methods of cultivation. It was observed that for calculating the crop duration GDD is better method than duration in days. From the growing degree days of 32 genotypes, it was found that GDD varied from 1085 to 1374 under SRI method and 1064 to 1420 in traditional method in different genotypes. The grain yield was highest in respect of genotype R-1124-91-2-73-1 (645.8 g m^{-2}) in SRI method of cultivation which had the highest thermal use efficiency. In the case of SRI method of rice cultivation the age of seedling was 12 days at time of transplanting whereas in traditional method of cultivation the age of seedling was 21 days. This difference of 9 days continued till

50 % flowering with slight genotypic variation. From the recording of GDD, the same trend had been observed. In fact the growing degree days required in the traditional method of cultivation was slightly higher in all the genotypes as the duration was longer. But the difference in GDD was not as much as the difference in duration. This seems to be a good indication that the GDD method of computing the duration was better method than counting the days.

Priyadarshi *et al* (2018) conducted an experiment at Research Farm of Odisha University of Agriculture and Technology, Bhubaneswar, India to study the different agro-meteorological indices and phenology. The growing degree days (GDD) and heat use efficiency (HUE) were calculated for rice variety 'Hasanta' cultivated under different dates of transplanting i.e. 10^{th} July, 20^{th} July, 30^{th} July and 10^{th} August with different doses of nitrogen application. Heat units required to attain different phenological stages decreased in all the varieties with delay in transplanting date. The study showed that maximum calendar day, growing degree days and heat use efficiency was highest in the crop transplanted on 10th July followed by 20^{th} July and 30^{th} July. Further it was concluded that the crop with 125% nitrogen application had accumulated highest heat units in all phenophases followed by 100% nitrogen. The reason assigned to it was that under higher level of nitrogen and early planting, the crop took more number of days to mature.

Pallavi *et al* (2018) carried out an experiment at Norman E. Borolaug Crop Research Centre & Department of Plant Physiology, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand on evaluation of growing degree days values of early, normal and late sowing dates in different genotypes of rice (*Oryza sativa* L.) for the heat efficiency estimation of rice crop. Three sowing dates were taken viz.25^{th} May (Early sown), 12^{th} June (normal sown), 27^{th} June (Late sown) and fifteen rice genotypes. From this study, it was concluded that the genotypes sown early accumulated more heat units and gave best result in term of yield parameters when compared with normal and late sown genotypes.

Malo *et al* (2018) conducted an experiment at Department of Agronomy and Department of Agricultural Meteorology and Physics at Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India to study the growing degree days (GDD) and to assess the effect of inorganic fertilizer as well as bio-fertilizers on thermal use efficiencies of rice in terms of dry matter accumulation and grain yield in New Alluvial Zone of West Bengal during *kharif* season of 2016. It was observed that in Shatabdi cultivar the lowest growing degree days (GDD) requirement was in case of attaining dough stage but the other stages like active tillering, panicle initiation, booting, heading, anthesis, milking and maturity need increasing trend of growing degree days (GDD) requirement with the maximum value recorded for the attainment of active tillering stage.

Banerjee *et al* (2018) conducted an experiment at Department of Agronomy and

Department of Agricultural Statistics, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India on the phenological development and thermal unit requirements of seven aromatic rice landraces of West Bengal during *kharif* (wet) season of 2008 and 2009. All seven indigenous scented rice cultivars were long duration types (140.0-148.3 days). For all seven cultivars the accumulated GDD were slightly higher during 2009 than 2008. It was mainly due to longer vegetative phase along with greater air temperature and photoperiod during the period. The correlation studies revealed that GDD and HTU had positive influence on number of panicle m^2 at tiller production stage, while Heliothermal Units showed positive impact at ripening stage (grain filling and development) leading to higher grain yield. The regression model for grain yield revealed the associations of GDD and HTU both during milk to dough stage and accounted for 34 per cent variation at 1 per cent level of significance.

Murari *et al* (2018) conducted a research on extreme temperatures and crop yields in Karnataka, India. Data model based on taluk-level fixed effects panel was used to study the impact of extreme temperature, estimated in terms of extreme degree days, on crop productivity on different *kharif* crops. In this model, crop yield was considered as dependent variables and growing degree days (GDD), total seasonal rainfall and extreme degree days (EDD) as independent variables. It was found that an inverse linear relationship exists between yield and extreme degree days showing that the greater effect of extreme temperature on yields (EDD) than the impact of rainfall and GDD. The yields were significantly low in cropping seasons due to exposure to temperatures above the critical thresholds level depicting the extreme temperature days exerting additional pressure on the agricultural production in the state.

Kar *et al* (2018) studied thermal requirement of different rice cultivars as influenced by planting methods and water regimes. This experiment was carried out at Research farm of Orissa University of Agriculture and Technology (OUAT), Bhubaneswar, Odisha during dry (January-May) and wet (June-October) seasons. The treatments included two establishment methods i.e. dry drill direct seeded rice (DSR) and non puddle transplanted rice (NPTR), three water regimes viz. no stress i.e. irrigation upto 5cm depth was applied to the field as soon as the ponded water disappeared, 10kPa and 40kpa (irrigation was applied based on the tensiometer data and five cultivars viz. Lalat, Sahbhagi Dhan, Arize 6129, US323 and Arize 6444. As regard to accumulated GDD, it was higher in wet season than in dry season because the initial month after sowing coincided with average low temperature. This lead to more GDD accumulation in wet season than dry season. In the establishment method accumulated GDD was more in NPTR in both the seasons. With the regard to water regime, as the water stress increased the number of days for the attainment of phenophases increased and hence the GDD accumulation was more. Among cultivars, highest GDD was accumulated by Arize 6444 in the dry season and wet season. Heat use efficiency i.e. grain yield obtained per unit of

GDD was higher in dry season than wet season. The agro meteorological indices viz. GDD, HTU and HUE provide a scientific basis for determining the effect of temperature and sunshine hours on the performance of crop. Arize 6444 being a long duration crop has the ability to accumulate higher photoperiod hours at maturity and yielded higher grain yield.

Sharma *et al* (2019) carried out study of phenophasic climatic requirement for maximum yield of rice in the prevailing weather conditions. A field experiment was conducted during *kharif* season of 2017-18 at N.D. University of Agriculture and Technology, Kumarganj, Faizabad (U.P.). The experiment consisted of nine treatment combinations comprised of three transplanting dates viz. July 5th, July 15th and July 25th and three varieties viz., NDR-97, NDR-3112 and BPT-5204. Results revealed that the different phenophases of rice markedly varied with only dates of transplanting but also different weather variables which ultimately created the different crop growing environment to harvest the yield accordingly. Highest Growing Degree days (GDD), Highest heliothermal and photothermal unit, maximum heat use efficiency HUE was recorded in growing environment of July 5th due to occurrence of long duration. Among the varieties, NDR-3112 possessed highest heat use efficiency at 105 DAT followed by BPT-5204 and NDR-97.

Medhi *et al* (2019) carried out an experiment at Instructional cum Research (ICR) Farm of Assam Agricultural University, Jorhat, Assam the two cultivars of rice viz. Luit and TTB-404 were chosen and grown in different micro climatic regimes created by manipulating the sowing as well as transplanting dates. The four different dates of transplanting were chosen i.e. 26th June, 11th July, 26thJuly and 10thAugust. Agroclimatic indices viz., Growing Degree Days (GDD), Heliothermal Unit (HTU), Phenothermal Index (PTI) and Heat Use Efficiency (HUE) for attaining different phenological stages in both the cultivars were studied. TTB- 404 accumulated higher GDD at physiological maturity under different dates of sowing. Comparatively, in cultivar Luit, higher grain yield was recorded in the crop sown on D2 (11th July) and D3 (26th July), while in TTB-404 it was recorded in D2 (11th July) and yield in both the cultivars declines gradually with crop transplanted beyond first fortnight of August. Furthermore, the grain yield of both the cultivars was significantly correlated with accumulated GDD and HTU during transplanting to maximum tillering stage with correlation coefficients (r) 0.92** and 0.72* respectively.

2.2 Effect of changing climate on rice phenology, heat units and yield of rice

Rani *et al* (2013) carried out a study with the objective to provide an overview of the influence of elevated temperature on rice phenology and accumulated growing degree days. The experiment was carried out under temperature control chamber, in which for the entire duration of crop, temperature was increased from the ambient level (2°C and 4°C). The results revealed that the days taken to attain maturity was 108 under normal air temperature and less under high temperature of 4°C (96 days) and 2°C (102 days). The accumulated growing degree days were higher under elevated temperature of 4°C as compared to 2°C and ambient but the yield was 23 and 13.3 percent less from the ambient under high temperature of 4°C and 2°C.

Singh *et al* (2012) studied impact of climate change on rice phenology and performance in terms of grain and above ground biomass yield under semiarid condition of Kanpur. The experiment was conducted with the objective to study the response of prevailing environments and their interaction with Photosensitive (mahsoori) and photoinsensitive (Ashwani and Pant-4) genotypes. The results showed that first year environmental conditions were more favourable for growth and development (vegetative growth). The second year was better for economic produce (grain yield) probably due to the optimum environmental conditions during reproductive phase. Under different transplanting dates there was significant variation in thermal time reaquirements (TTR) from sowing to tillering (second year) and from anthesis to maturity during both the years. There was drastical reduction in all the yield deciding components with each delay in transplanting except panicle length and 1000-seed weight (second year). Mahsoori (longer duration) genotype accumulated more heat units between phenological stages than medium duration genotypes Pant- 4 and short duration Ashwini during both the years. During both the years genotype Mahsoori produced significantly higher above ground biomass than other tested varieties. However, grain yield was significantly higher in ashwani and pant-4 as there was higher harvest index due to better converters of photosythates to economic produce. This might be due to congenial weather conditions during reproductive stages as it was also reflected by mean effect.

Wang *et al* (2014) studied temperature variations and rice yields in China: historical contributions and future trends. To capture the different effects of normal and extreme temperatures on rice yields they made use of normal growing degree days (NGDD) and killing growing degree days (KGDD), respectively. Assessment was done for contributions of temperature variations to county-level rice yields across China during the historical period (1980–2008) and estimated the potential exposure of rice to extreme temperature stress in the near future (2021–2050). The results showed that historical temperature variations had measurable impacts on rice yields with a distinct spatial pattern: for different regions, such variations had increased rice yields in Northeast China (Region I) and some portions of the Yunnan-Guizhou Plateau (Region II). There had been no improvements of rice yields in the Sichuan Basin (SB) and the southern cultivation areas (Region IV). The results showed that historical temperature variations had contributed much to the increased rice yields with an average of 0.01 per cent yield year. Under the RCP8.5 scenario, climate warming during 2021–2050 would substantially reduce cold stress but increase heat stress in the rice planting areas across China. For the future period, Region I, II and eastern China would be continually exposed to more severe cold stress than the other regions; Region III (including SB and the mid-lower reaches of Yangtze River (MLRYR)) would be the hot spot of heat stress.

Karki *et al* (2015) conducted a study at farmer's field in Dhobadi in Nepal on drought tolerant rainfed rice cultivars to staggered transplanting dates under changing climatic scenarios of central terai, Nepal. It was found that different dates of transplanting have significant effect on grain yield while varietal differences were found to be non-significant. GDD received by rice cultivars was found significantly higher (2830°C) for July 15 transplanted rice whereas, August 14 transplanted rice received significantly lower GDD (2689°C) for maintaining maturity stage The crop transplanted on 15th June produces maximum yield. Grain yield attributes were statistically at par under July 15, July 25 and August 4 transplanted condition and significantly superior over August 14 transplanting. Among all the cultivars Sukkha Dhan-2 was relatively more stable in using heat for all transplanting dates followed by Sukkha Dhan-3, Sukkha Dhan-1 and Radha-4. There is significant effect of transplanting dates and cultivars on Growing degree days (GDD) at different phenological stages of drought tolerant rice. In context of changing climatic scenario under rainfed condition in central terai of Nepal, the drought tolerant rice cultivars can be transplanted within July to escape the effect of late season drought on critical growth stages.

Modarresi *et al* (2015) made a study at Department of Engineering, Yadegar-e-Imam Khomeini (RAH), Shahre-Rey Branch, Islamic Azad University Tehran, Iran by using a map of the rice plant phenology and meteorological data, on the growth stages of Khazar rice in Gilan province. The study revealed that in 2013 crop year, the cumulative degree day was reduced along with delay in date of occurrence of plant phenology as compared with normal crop year. The increase in air temperature in 2013 caused the reduction in the length of growing season and other stages of plant growth which effect yield in normal crop year.

Kaur (2016) conducted a study at Department of Climate Change and Agricultural Meteorology on assessment of climate variability impact on productivity of rice in Punjab using Geospatial Technology. Different regions of the Punjab state showed large variation in rice productivity during 1974-2013. South-west region gave higher yield followed by central region and then north-east region. Similar, trends were observed for maximum temperature and minimum temperature. Climate change in different districts and time period of state is responsible for minimum temperature variation.

Kingra (2016) carried out an experiment at Department of Climate Change and Agricultural Meteorology on climate variability and impact on productivity of rice in central Punjab by developing agrometeorological rice yield forecasting models in order to quantify the influence of climatic variations on rice productivity. A study was initiated and they found that due to fluctuations in weather conditions, large variability in crop yield was observed in the region from year- to-year. Analysis of long-term climatic variability showed no significant variation in maximum temperature, but there was significant increase in minimum temperature (@ 0.05°C/year). Agrometeorological models can be used very effectively for pre-harvest crop yield prediction and policy planning for ensuring food security under changing climatic scenarios.

2.3 Spatio-temporal variability thermal requirement of rice

Zhang *et al* (2013) studied spatio-temporal reconstruction of air temperature maps and their application to estimate rice growing season heat accumulation using multi-temporal MODIS data. The accumulated heat units usually represents the local heat resources to drive crop growth. The maps were generated based on spatial interpolation of temperature-based agro-meteorological indices. From MODIS land surface temperature (LST) data the accumulative growing degree days (AGDDs) above 10 °C was calculated. In the study spatial distribution of the AGDD anomalies for Jilin Province of rice growing season from 2001 to 2010 was mapped. The positive AGDD anomalies with warm colors (red, orange) indicated a greater heat accumulation of specified year than the normal level based on the average of the recent 10 years. The negative AGDD anomalies represented in cool color (light and dark blue) mean lower heat accumulation where there was probably a growth delay for rice reaching harvest. The study may supply a novel way to calculate AGDD in heat-related study concerning crop growth monitoring, agricultural climatic regionalization, and agro-meteorological disaster detection at the regional scale.

Huang *et al* (2013) studied spatio-temporal reconstruction of air temperature maps and their application to estimate rice growing season heat accumulation using multi-temporal MODIS data. Maps of temperature-based agro-meteorological indices were commonly generated by the spatial interpolation of data collected from meteorological stations and remotely sensed data from Terra and Aqua moderate resolution imaging spectroradiometer (MODIS). This study was carried out to calculate heat accumulation, expressed in accumulative growing degree days (AGDDs) above 10°C. Estimation of GDDs reaching a certain threshold is used to to monitor crop growth and identify crop phenological stages.

Raza *et al* (2018) conducted a study on temperature based spatiotemporal growth monitoring of rice plant from germination-ripening stage using remote sensing and GIS techniques in different districts of Punjab state of Pakistan. Global warming has a profound impact on rice crop phenology. To calculate pixel based temperature values, Landsat 7 and 8 thermal dataset was used to evaluate growth using agricultural growth indicators. Low temperature caused the delay in rice plant growth and very high temperature led to stressed and short heighted plant. High temperature was experienced by rice plantation which was near to cities and road network due to high concentration of environmental pollution.The crop near to water body e.g. Rivers, Canals and Nalas, experienced comparatively low temperature that resulted in slow growth rate. So they concluded that rice plantation sown at same time is not ready for harvest at the same time due to delay heat units experienced by a single rice plant. However, with such high temporal resolution data, best results regarding growth monitoring against each growth data were obtained.

Raza *et al* (2018) conducted a reaserch on delineation of potential sites for rice cultivation through Multi-Criteria Evaluation (MCE) using remote sensing and GIS. Considering the climatic and physical factors the suitable land can be mapped for rice cultivation. Moderate Resolution Imaging Spectro-radiometer (MODIS) time series datasets of rice cultivation season was calculated. Landsat 8 thermal datasets were obtained for the rice cultivation season and temperature based growth variability maps were generated. To examine the rate of plant development Growing degree days (GDD) was used as temperature based indicator across the study area. From the temperature values it was concluded that temperature less than 15 °C and above (40-45) °C were not suitable for any development stage of rice plant and temperature values highly suitable for different phenological stages are germination (22-32) °C, flowering, milky dough (25-30) °C and ripening stage (18-28) °C. Temperature based suitability zones for rice crop were mapped Multi-criteria evaluation (MCE) techniques. The map was generated using Spatial Analyst tools in Arc GIS 10.1 Spatial analytical techniques in Arc GIS 10.1 are useful to identify suitable sites for rice cultivation. Multi-criteria evaluation using analytical hierarchy process makes a decision and policy maker capable enough to make a fruitful policy to get enhanced rice crop yield. The main purpose of this comparison was to delineate the actual rice cultivation area in less suitable, moderately suitable, highly suitable and not suitable zones.

CHAPTER-III

MATERIALS AND METHODS

In order to achieve the objectives of the study, experiment entitled **"**Delineation of thermal requirements of rice (*Oryza sativa* L.) staggered in different transplanting windows and their validation**"** was conducted during 2019-20. The details of material and techniques used during experiment are presented in the chapter under the given heads and sub-heads:

3.1 LOCATION OF WORK

- Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana.
- Punjab Remote Sensing Centre, Ludhiana.

3.2 PUNJAB AND ITS ADMINISTRATIVE SET- UP

Punjab state forms a part of the northwestern India extending from 29°30' to 32°32' North latitude and 73°55' to 76°50' East latitude. The state is bordered by Himachal Pradesh to the east, Punjab state of Pakistan to the west, Rajasthan to the southwest, Haryana to the south and southeast and Jammu and Kashmir to the north. The state comprises of 1.53 per cent of the total geographical area of India with total area of 50,362 sq. km (Anonymous 2018).

3.3 CLIMATE

The large variations in temperature from month to month are due to subtropical latitudinal location and geography of Punjab. Mid-May and June usually experiences the maximum temperature, remaining above 40°C during this period in the whole region. The minimum temperature is recorded from December to February, remaining below 5°C for almost two months during the winter season.

Table 3.1: Mean monthly meteorological data recorded at Agrometeorological observatory during *Kharif* 2019-20

Month	Temperature (°C)		Relative Humidity (%)		Rainfall (mm)	Rainy Days	Wind Velocity (km/hr)
	Max	Min	M	E			
May	38.0	22.1	52	22	10	2	4.6
June	40.4	26.9	55	30	29.9	1	6
July	34.0	26.9	79	64	218.4	10	5.7
August	35.2	27.6	85	67	331.4	8	3.5
September	33.2	25.5	86	68	264.8	7	3.3
October	30.6	18.4	90	46	0	0	2.8

Max: Maximum temperature (°C) M: Morning relative humidity
Min: Minimum temperature (°C) E: Evening relative humidity

The state endures three main seasons. Hot season starting from April and terminates to the end of June, rainy season starting from early July and terminates to the end of September and cold season starting from early December and terminates to February end. The rainfall for the region is mostly provided by the monsoon season ranging from 250 mm to 1000 mm. The monsoon rainfall in the state is essential for growing the *Kharif* crops. The Shivalik Hills experiences the maximum falling and the desert in the west experiences the minimum falling.

3.4 DATA COLLECTED

a) Weather data:

The data with respect to maximum and minimum temperature was collected from

- Department of Climate Change and Agricultural Meteorology.
- India Meteorology Department, Chandigarh.
- MarksimGCM software.

b) Crop Data: District wise data of rice productivity was collected from statistical abstracts of Punjab published by Economic & Statistical Organization (ESO), Government of Punjab.

3.5 FIELD EXPERIMENT

A field experiment was conducted to assess the thermal requirements of rice under staggered planting with following treatment details:

Treatment details	
Crop	Rice (*Oryza sativa* L.)
Variety	Three
	V_1 - PR115
	V_2 - PR118
	V_3 - PR124
Date of Transplanting	Three
	D_1 - 13 June
	D_2 - 21 June
	D_3 - 29 June
Design	Randomized block design (RBD)
Replications	Three
Total No. of Plots	27

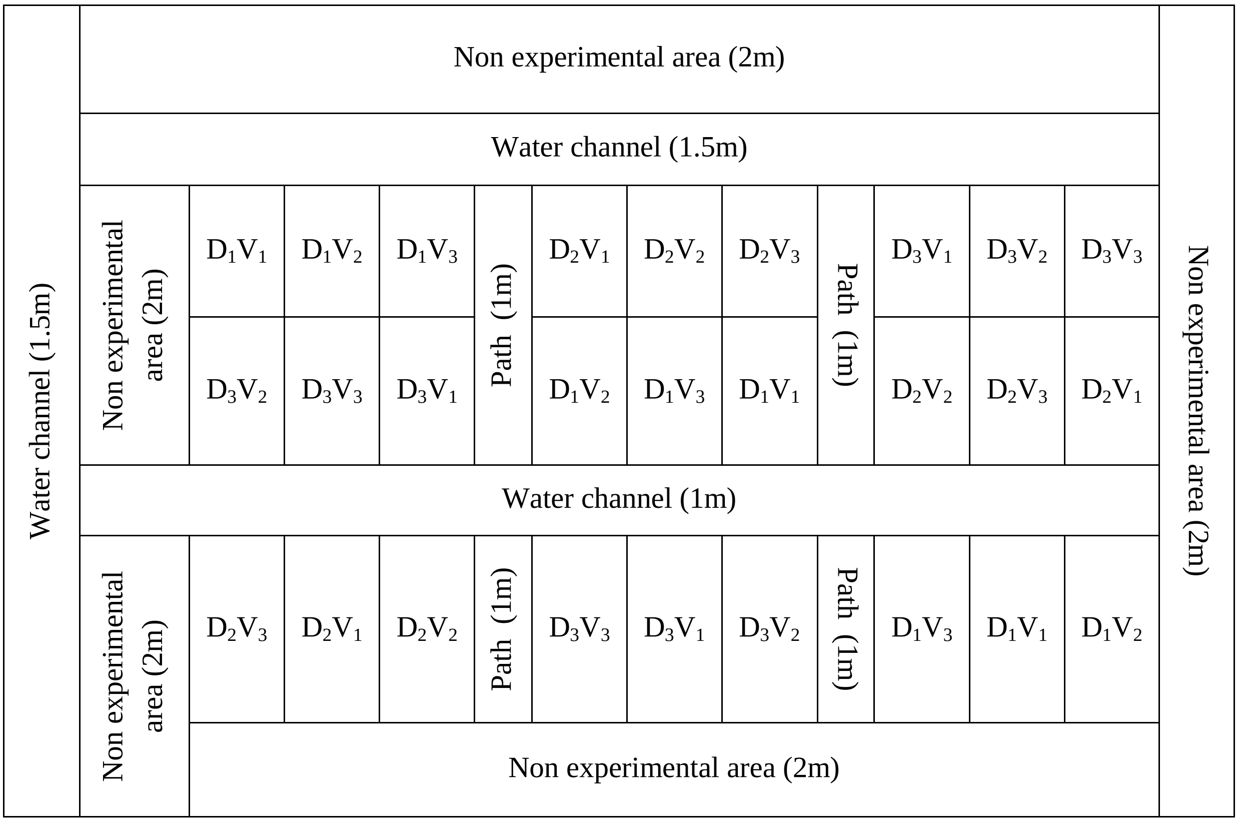


Fig. 3.1: Layout plan of experiment

3.5.1 Cropping history

Table 3.2: Cropping history of the experimental field

Year	**Crop season**	
	Kharif	***Rabi***
2017-18	Rice	Wheat
2018-19	Rice	Wheat

3.5.2 Cultural operations

a) Field preparation

With the disc harrow the experimental field was ploughed twice followed by planking. The field was irrigated and puddled with cultivator and in the last planking was done twice in standing water.

b) Nursery Preparation

Nursery beds were prepared by ploughing the field twice. Small sized seed beds were prepared. The pre germinated seeds of PR115, PR118 and PR124 were sown by broadcasting on field. The seedlings were given frequent light irrigation.

c) Transplanting

For transplanting, light irrigation was applied before uprooting the seedlings. The seedlings were transplanted on June 13^{th} June, 21^{st} June and 27^{th} June in well puddled field at specific interval (20 cm x 10 cm).

d) Fertilizer Application

The fertilizers were applied at a rate of 90kg urea per acre, SSP 75kg per acre and MOP 20kg per acre and 25 kg zinc sulphate heptahydrate. First half of nitrogen was applied as basal dose and the rest half in two split at 20 and 40 DAT. Whole dose of phosphorus, potash and zinc was applied as basal at time of puddling.

e) Weed Management

Two hand weedings were done at 15 days intervals after 15 days after transplanting.

f) Harvesting and Threshing

The crop was harvested at physiological maturity and was dried under the sun before threshing.

3.5.3 Meteorological observations

- **Maximum and minimum temperature (°C)**

The maximum temperature was recorded at 1430 and minimum temperature at 0730 hours, with thermometers kept in Stevenson's Screen.

3.5.4 Micrometeorological observation

- **Photosynthetically active radiation**

Photosynthetically active radiations were recorded at two hour interval from 1000 hours to 1600 hours at different phenological stages. Line Quantum Sensor (Model LI-190 SB) was used to measure the amount of incoming, reflected and transmitted PAR

Digital multivoltmeter was used for the recording of output of Quantum Sensor. For recording of incoming and outgoing radiations, the instrument was kept at 1 meter above from the crop canopy, while transmitted radiations were recorded by keeping the instrument just above the ground level in the crop canopy.

PAR interception by the crop was calculated with the help of following formula:

$$\text{PAR interception (\%)} = \frac{\text{PAR(I)} - [\text{PAR(T)} + \text{PAR(R)}]}{\text{PAR(I)}} \times 100$$

Where,

PAR (I) – PAR incoming above the canopy

PAR (T) – PAR transmitted to the ground

PAR (R) – PAR reflected from the canopy

3.5.5 Phenological observations

The time of occurrence of different phenological stages viz. maximum tillering, booting, 50% panicle initiation, anthesis, grain filling and physiological maturity were observed visually and noted.

a) Tillering: During this time period the seedling produces tillers after the fifth leaf emergence. The number of tillers increases till maximum tillering.

b) Maximum tillering: At this stage, it may become difficult to distinguish the main culm from the tiller.

c) Booting: At this stage, the sheath of flag leaf get swelled that is due to the enlargement of the panicle.

d) Heading: Panicle emerge from the bottom of flag leaf. This stage can last for 10-14 days. "Heading date" is defined as the time when at least 50 per cent of the panicles have at least partially exserted from the boot.

e) Anthesis (Flowering): It is characterised by opening and closing of the floret and it may take 1 to 2½ hours. On an average it occurs three days after heading.

f) Ripening: It is the maturation stage followed by ovary fertilization and grain growth.

g) Milk stage: During this developing stage, kernel is filled with white liquid resembling milk.

h) Soft dough stage: The starch in the grain become firm but is still soft.

i) Hard dough stage: The whole grain is firm and ready for harvest almost.

j) Maturity: At maturity the grain is hard and ready for harvest. Now the moisture per cent in grains is 20 to 22 percent.

3.5.6 Statistical analysis

The data collected with respect to yield and transplanting dates were statiscally analysed by using factorial randomized block design in Elementary Design Application (EDA 1.1).

3.6 COMPUTATION OF LONG TERM HEAT UNITS, HEAT USE EFFICIENCY OF RICE AND ITS SPATIAL INTERPOLATION

- **Accumulated Growing Degree Days (GDD)**

Accumulated Growing degree days was computed by using the following formula:

$$\text{AGDD} = \sum_{i=1}^{n} \frac{T_{\max} + T_{\min}}{2} - T_b$$

Where,

AGDD	=	Accumulated Growing degree days (°C day).
T_{max}	=	Maximum temperature (°C) of the day.
T_{min}	=	Minimuum temperature (°C) of the day.
T_b	=	Base temperature 10°C (Ghadekar 1991)

- **Heat Use Efficiency (HUE)**

Heat use efficiency was calculated by following formula:

$$\text{HUE (kg/ha/°C day)} = \frac{\text{Yield (kg/ha)}}{\text{Accumulated GDD (°C day)}}$$

3.7 VALIDATION OF THERMAL REQUIREMENTS WITH ACTUAL EXPERIMENTAL DATA

Historical data was validated with the experimental data of three phenological stages viz. Maximum tillering, Anthesis and Physiological maturity by using following formula:

$$\% \text{ Deviation} = \frac{\text{Experimental value of AGDD} - \text{Historical value of AGDD}}{\text{Historical value of AGDD}} \times 100$$

The past trends for the time series as per table given below was generated and thermal requirements was computed.

Time series	Range of the data for analysis
P_1	1990-1994
P_2	1995-1999
P_3	2000-2004
P_4	2005-2009
P_5	2010-2014
P_6	2015-2019

3.8 SPATIAL INTERPOLATION

Spatial interpolation of accumulated growing degree days of rice was done with help of software Arc GIS 10.2 by using Inverse Distance Weighted Method (IDW). It is a technique of spatial interpolation based on group of known scattered points from which value of unknown points are calculated.

3.9 EFFECT OF FUTURE CLIMATE CHANGE ON THERMAL REQUIREMENTS OF RICE

Future climate trends were generated by using Marksim GCM for obtaining the future temperature trends. Marksim GCM gives the output for 17 models along with average of 17 models. The future trends for the time series as per table given below was generated and thermal requirements was computed.

Future trends of the thermal requirements

Time series	Range of the data for analysis
F_1	2020-2024
F_2	2025-2029
F_3	2030-2034
F_4	2035-2039
F_5	2040-2044
F_6	2045-2049

Deviation of future accumulated growing degree days (AGDD) from present were calculated for three phenological stages viz. CRI, flowering and maturity by using following formula:

$$\% \text{ Deviation} = \frac{\text{Future AGDD value} - \text{Experimental AGDD value}}{\text{Experimental AGDD value}} \times 100$$

CHAPTER-IV

RESULTS AND DISCUSSION

The results of the present study entitled "Delineation of thermal requirements of rice (*Oryza sativa* L.) staggered in different transplanting windows and their validation" obtained from historical, present and future data analysis regarding the trends of thermal requirements of rice on geo-spatial domain has been presented in the graphs, tables and maps generated through Arc GIS 10.2 are discussed under the following headings and subheadings:

4.1 Effect of dates of transplanting on rice crop

- 4.1.1 Effect of dates of transplanting on the phenology of rice.
- 4.1.2 Effect of dates of transplanting on the accumulation of growing degree days at various phenological stages of the rice.
- 4.1.3 Effect of dates of transplanting on PAR interception at different phenological stages of the rice crop.
- 4.1.4 Effect of dates of transplanting on grain yield of rice.

4.2 Spatio-temporal variability in thermal requirements of rice in Punjab under three transplanting windows (1990 to 2019)

- 4.2.1 Trend analysis of accumulated growing degree days of rice under transplanting window I.
- 4.2.2 Trend analysis of accumulated growing degree days of rice under transplanting window II.
- 4.2.3 Trend analysis of accumulated growing degree days of rice under transplanting window III.
- 4.2.4 Variability in accumulated growing degree days at different phenological stages of rice during different pentads under different transplanting windows.
- 4.2.5 Trend analysis of heat use efficiency of rice under transplanting window I.
- 4.2.6 Trend analysis of heat use efficiency of rice under transplanting window II.
- 4.2.7 Trend analysis of heat use efficiency of rice under transplanting window III.
- 4.2.8 Variability in heat use efficiency of rice in Punjab during different pentads in different transplanting windows.

4.3 Spatio-temporal variability in thermal requirements of rice in Punjab under three transplanting windows from 1990 to 2019 by using geospatial technology

- 4.3.1 Spatio-temporal variability in thermal requirements of rice under transplanting window I.
- 4.3.2 Spatio-temporal variability in thermal requirements of rice under transplanting window II.

4.3.3 Spatio-temporal variability in thermal requirements of rice under transplanting window III.

4.4 Validation of historical thermal requirements of rice with actual experimental data in staggered transplanting.

4.5 Predicted spatio-temporal variability in thermal requirements of rice as affected by different transplanting windows.

4.1 EFFECT OF DATES OF TRANSPLANTING ON RICE CROP

4.1.1 Effect of dates of transplanting on the phenology of rice

Phenology is the phasic development of crop with respect to the surrounding environment. It is the study of cyclic and seasonal natural phenomena, especially in relation to climate and plant life. The expression of plant depends on many factors like heredity, temperature, photoperiod and nutrition etc. The duration of each phenophase determines the accumulation and partitioning of dry matter in different parts (Dalton 1967).

The data regarding the days taken by different rice varieties to reach different phenological stages i.e. maximum tillering, booting, 50% panicle initiation, anthesis, grain filling and physiological maturity, transplanted under three growing environments is presented in Table 4.1. The crop showed the variation in attaining the phonological stages because of variation in weather conditions viz. temperature and relative humidity in the atmosphere during the crop growth and phenophasic change based on change in growing environment. Thus, the crop transplanted on 13th June (D_1) took more number of days to reach physiological maturity stage as compared to delayed growing environment on 21st June (D_2) and 29th June (D_3). The early transplanted crop took more number of days to reach different phenological stages. The reason might be that early crop experienced more optimum temperature conditions for flowering and maturity as compared to late sown crop. These statements are agreeing with the finding of Netam 2017.

Table 4.1 : Phenology of rice crop under three transplanting windows

Phenology	Transplanting Window I	Transplanting Window II	Transplanting Window III
Transplanting	13 June	21 June	29 June
Maximum tillering	17 July	30 July	7 August
Booting	8 August	17 August	28 August
50% Panicle initiation	23 August	2 September	8 September
Anthesis	26 August	4 September	10 September
Grain filling	13 September	20 September	25 September
Physiological maturity	28 September	2 October	6 October

4.1.2 Effect of dates of transplanting on the accumulation of growing degree days at various phenological stages of the rice crop

Growing degree days (GDD) is a simple temperature-based index of biological development (Hassan *et al* 2007) based on the concept that there is linear relationship between right time for the attainment of certain phenological stages and temperature ranging between mean temperature and base temperature. Growing degree day is an index used in agriculture to estimate sowing time and date of occurrence of different phenological stages. It is a heat index that enables us to predict maturity dates. Under field conditions temperature influence on development and yield of crop plants is studied through accumulated heat unit system as plants have a distinct temperature requirement prior the attainment of certain phenological stage. The accumulation of thermal time usually represents the local heat resources to drive crop growth.

Table 4.2: Accumulated growing degree days (AGDD) in variety PR 115 under different dates of transplanting

Phenology	13 June		21 June		29 June	
	Days	AGDD	Days	AGDD	Days	AGDD
Transplanting	0	19.8	0	20.3	0	25.7
Maximum tillering	32	721.25	36	785.6	35	738.9
Booting	20(52)*	1115.2	13(49)*	1028.6	20(55)*	1142.9
50% Panicle Initiation	13(65)	1381.3	13(62)	1303.4	9(64)	1331.5
Anthesis	2(67)	1416.8	2(64)	1346.4	2(66)	1371.4
Grain filling	15(82)	1727.2	14(78)	1635.9	12(78)	1622.4
Physiological maturity	13(95)	1997.4	12(90)	1881.2	10(88)	1808.2

*Figures in parenthesis indicated the days after transplanting

AGDD - Accumulated growing degree days (°C day)

The accumulated Growing Degree Days (GDD) of different rice varieties under different growing environments from transplanting to maturity are shown in Tables 4.2, 4.3 and 4.4. Highest growing degree days (GDD) accumulation was recorded in D_1 growing environment in PR118 (2485°C day) at maturity stage. In case of PR115 the highest growing degree days (GDD) accumulation was observed under D_1 growing environment (1997°C day) followed by D_2 (1881°C day) and lowest was observed under D_3 growing environment (1808 °C day). Among the varieties, PR124 had accumulated highest heat units under D_1 (2164°C day) followed by D_2 (2076°C day) and D3 growing environment (1929°C day). Similarly in PR118 the highest value of accumulated growing degree days (GDD) was observed under D_1 (2485°C day) followed by D_2 (2344°C day) and D_3 growing environment (2214°C day). In general the accumulated growing degree days values decreased with delayed sowing due to early maturity of crop under delay sowing conditions. These results are in general agreement with the findings of Sreenivas *et al* 2010, Chopra and Chopra (2004) and Sandhu *et al* 2013.

Table 4.3: Accumulated growing degree days (AGDD) in variety PR 124 under different dates of transplanting

Phenology	13 June		21 June		29 June	
	Days	AGDD	Days	AGDD	Days	AGDD
Transplanting	0	19.8	0	20.3	0	25.7
Maximum tillering	34	755.3	38	866.3	38	738.9
Booting	22(56)*	1202.4	18(56)*	1223.6	20(58)*	1142.9
50% Panicle Initiation	14(70)	1477.3	16(72)	1495.2	12(70)	1371.4
Anthesis	2(72)	1520.3	2(74)	1532.5	2(72)	1411.5
Grain filling	17(89)	1873.6	16(90)	1863.4	15(87)	1717.8
Physiological maturity	15(104)	2164.0	12(102)	2076.0	12(99)	1929.8

* Figures in parenthesis indicated the days after transplanting

AGDD - Accumulated growing degree days (°C day)

Table 4.4: Accumulated growing degree days (AGDD) in variety PR 118 under different dates of transplanting

Phenology	13 June		21 June		29 June	
	Days	AGDD	Days	AGDD	Days	AGDD
Transplanting	0	19.8	0	20.3	0	25.7
Maximum tillering	36	794.2	42	884.8	44	864.9
Booting	24(60)*	1285.5	22(64)*	1324.9	24(68)*	1350.6
50% Panicle Initiation	18(78)	1647.6	19(83)	1721.6	14(82)	1641.6
Anthesis	4(82)	1727.2	4(87)	1804.4	3(85)	1699.2
Grain filling	22(104)	2164.0	18(105)	2128.2	18(103)	2006.5
Physiological maturity	20(126)	2485.4	14(119)	2344.0	14(117)	2214.1

*Figures in parenthesis indicated the days after transplanting

AGDD - Accumulated growing degree days (°C day)

4.1.3 Effect of dates of transplanting on PAR interception at different phenological stages of the rice crop

The microclimate of a crop stand is highly influenced by photosynthetically active radiation (PAR) interception. PAR is that part of electromagnetic spectrum which is used as source of energy for photosynthesis by green plants. Photosynthetically Active Radiation (PAR) is the amount of light available for photosynthesis, which is in the wavelength range of

400-700 nanometer.

The data of incoming, reflected and transmitted PAR was recorded at two hour interval at different phenological stages and PAR interception was calculated. Proper interception and transmission of PAR above and inside the crop canopy led to increase production levels. Generally, interception and efficiency of solar radiation are low during early developmental stages of crop and attains peak at vegetative phase and then again start to decrease as the crop progresses towards maturity. Interception of PAR was less during morning hours, then reached maximum at noon hours (between 1200 to 1400 hour) and then again started to decrease afterwards. The data on photosynthetically active radiation (PAR) interception (%) was taken at maximum tillering, booting, 50% panicle initiation, anthesis and grain filling (end) stages as shown in Figures 4.1, 4.2, 4.3, 4.4 and 4.5. Taking into consideration different dates of transplanting and phenological stages, the highest PAR interception of 88.2 per cent was recorded in case of 13th June transplant crop at flowering stage while minimum interception of 71.6 per cent was recorded for 29th June sown crop at grain filling stage. At 50% Panicle initiation stage, 13th June transplant recorded PAR interception of 85.8 per cent while 21st June, 29th June crop recorded 83.5 per cent, 81.1 per cent PAR interception respectively. At flowering, all dates of transplanting recorded PAR interception of >80 per cent. PAR interception of 88.2per cent, 86.3 per cent, 84.8 per cent was recorded for 13th June, 21 st June and 29th June transplanted crop respectively. In case of grain filling stage, maximum PAR interception of 75.15 per cent was recorded for13th June crop followed by21 st June and 29th June transplanted crop where PAR interception was 73.4 per cent, 71.6 per cent, respectively. Basu *et al* 2014 showed same result, PAR interception was highest at 1330 hour at 100% flowering and minimum at the tillering stage.

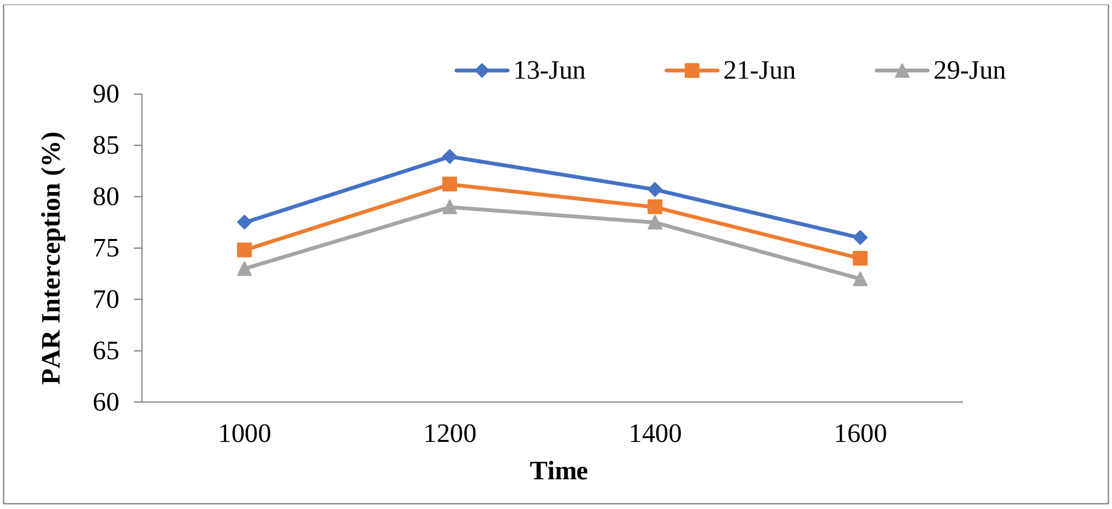


Fig. 4.1: Diurnal cycle of PAR interception (%) at maximum tillering stage under different dates of transplanting

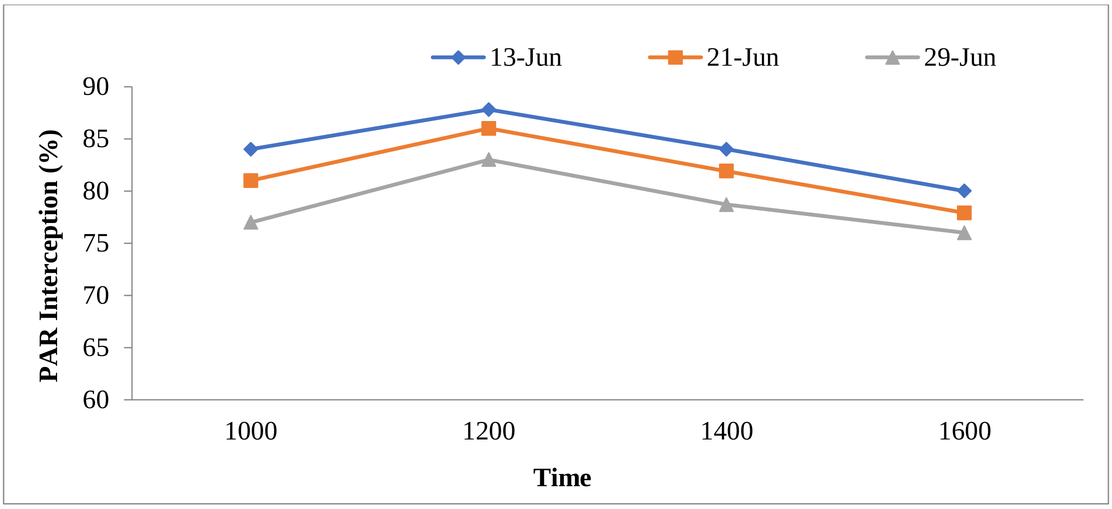


Fig. 4.2: Diurnal cycle of PAR interception (%) at booting stage under different dates of transplanting

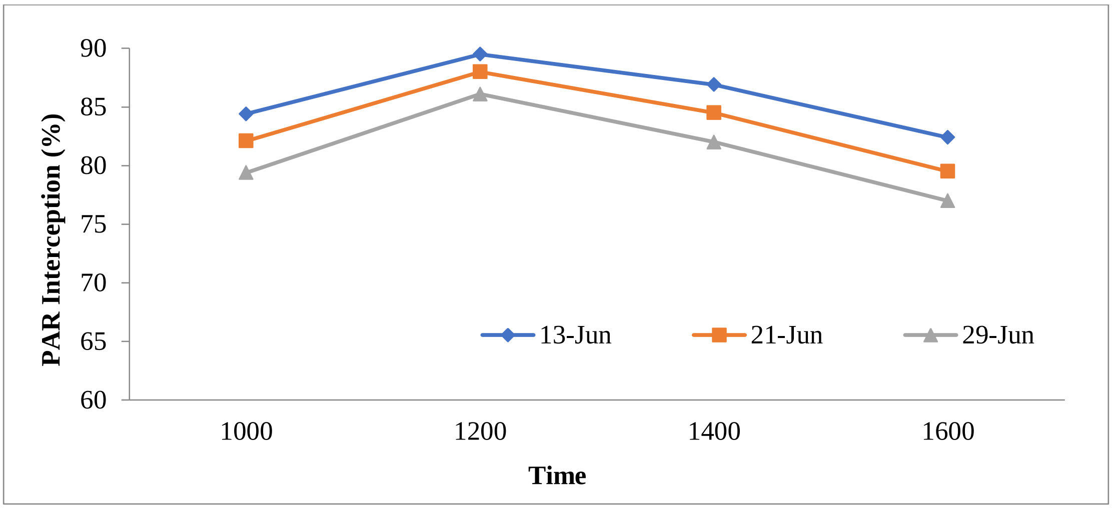


Fig. 4.3: Diurnal cycle of PAR interception (%) at 50% panicle initiation stage under different dates of transplanting

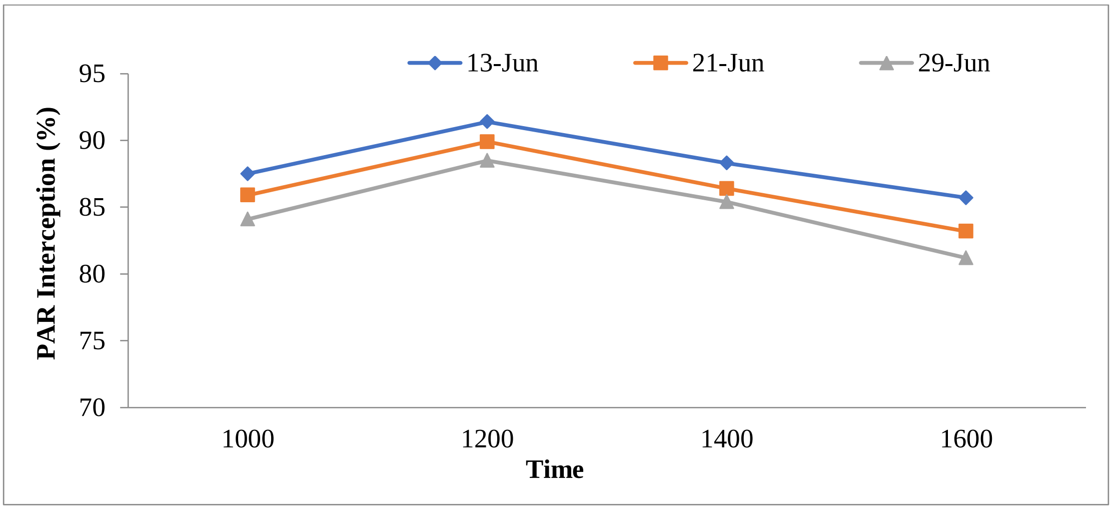


Fig. 4.4: Diurnal cycle of PAR interception (%) at anthesis stage under different dates of transplanting

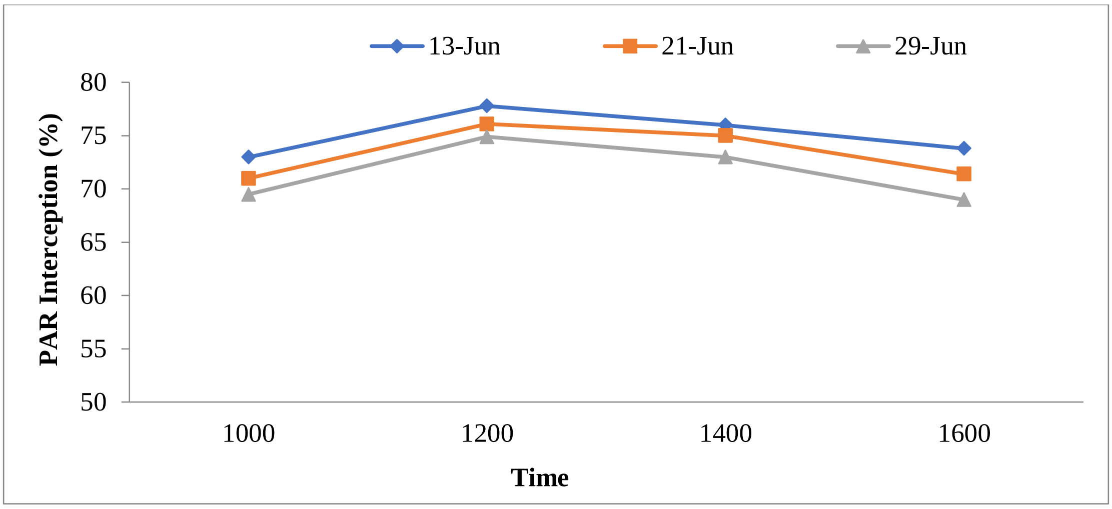


Fig. 4.5: Diurnal cycle of PAR interception (%) at grain filling stage under different dates of transplanting

4.1.4 Effect of dates of transplanting on grain yield of rice

Transplanting dates and varieties had significant effect on grain yield. Among the dates of transplanting, D_1 resulted in maximum grain yield but it was significantly at par with the grain yield produced by D_2 which in turn significantly at par with the grain yield produced by D_3. Analysis of variance showed sufficient variation among varieties in all growing environment and yield. The grain yield of cultivar PR 124 was significantly higher than the cultivar PR118 and PR115.The grain yield of cultivar PR115 was significantly low as compared to PR124 and PR118 (Sandhu *et al* 2013). PR124 is better than PR 118 and PR115 in utilizing the heat and sunlight available for growth, development and yield.

Table 4.5: Grain yield (q ha^{-1}) of rice cultivars under different dates of transplanting

Dates	Varieties			
	PR115	**PR118**	**PR124**	**Mean**
13 June (D_1)	68.6	72.4	75.7	72.2
21 June (D_2)	66.4	68.3	73.5	69.4
29 June (D_3)	62	68.2	71.2	67.1
LSD(0.05)	Dates		3.3	
	Varieties		3.3	
	Interaction		NS	

4.2 SPATIO-TEMPORAL VARIABILITY IN THERMAL REQUIREMENTS OF RICE IN PUNJAB UNDER THREE TRANSPLANTING WINDOWS (1990-2019)

4.2.1 Trend analysis of accumulated growing degree days of rice under transplanting window I

The data from 1990-2019 was analyzed for trends (increasing or decreasing) in accumulated growing degree days (AGDD) under transplanting window I and presented in Figures from 4.6 to 4.22. Variation in heat units was observed during different time period. It was observed that there was increasing trend of accumulated growing degree days (AGDD) in all the districts except Ludhiana and Bathinda where no such prominent increasing trend was found. The R^2 value was highest at Gurdaspur (0.74) and lowest at Bathinda (0.15). Among all the districts, the highest rate of AGDD increased was observed in S.B.S. Nagar (23.85ºC day year^{-1}) followed by Rupnagar (21.05ºC day year^{-1}) and Fatehgarh Sahib (19.25ºC day year^{-1}) and lowest was for Ludhiana (2.29ºC day year^{-1}) followed by Bathinda (2.48ºC day year^{-1}). The rate of increase was 14.74ºC day year^{-1} in Hoshiarpur, 0.37ºC day year^{-1} in Amritsar, 13.70ºC day year^{-1} in Kapurthala, 8.32ºC day year^{-1} in Jalandhar, 11.56ºC day year^{-1} in Moga, 15.44ºC day year^{-1} in Patiala, 12.39ºC day year^{-1} in Sangrur, 11.05ºC day year^{-1} in Faridkot, 11.10ºC day year^{-1}in Firozpur, in 12.25ºC day year^{-1} Muktsar, 15.25ºC day year^{-1} in Mansa.

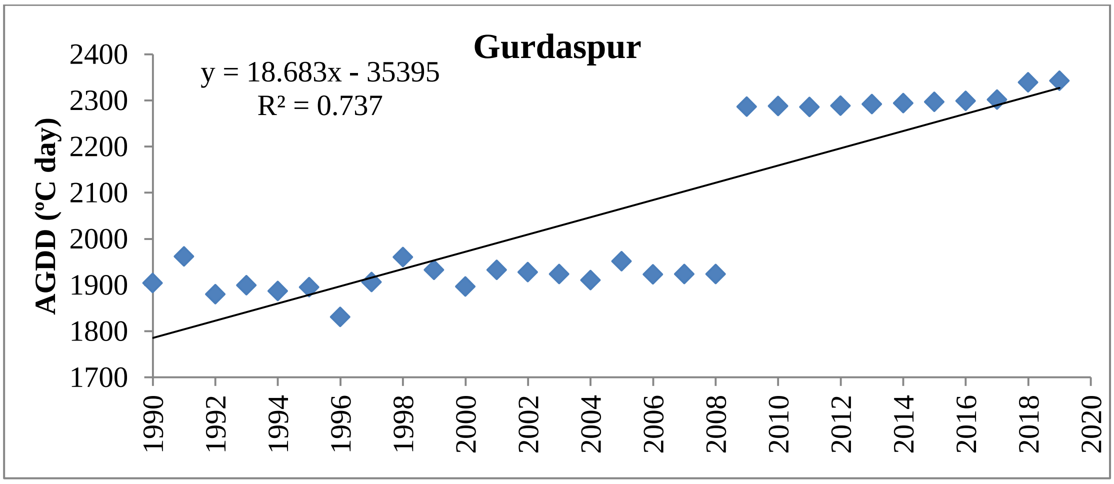


Fig. 4.6: Variability in annual AGDD from 1990 to 2019 at Gurdaspur under transplanting window I

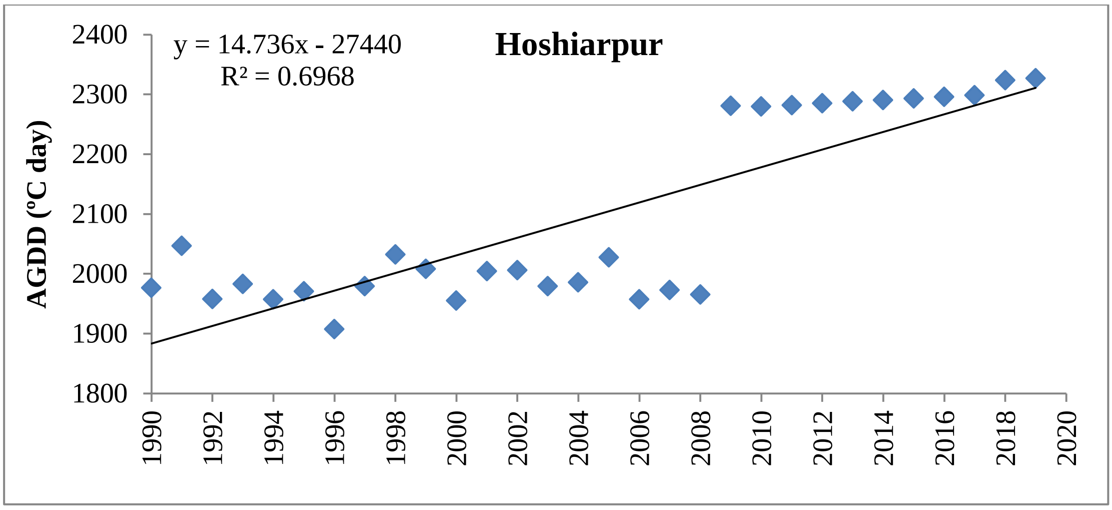


Fig 4.7: Variability in annual AGDD days from 1990 to 2019 at Hoshiarpur under transplanting window I

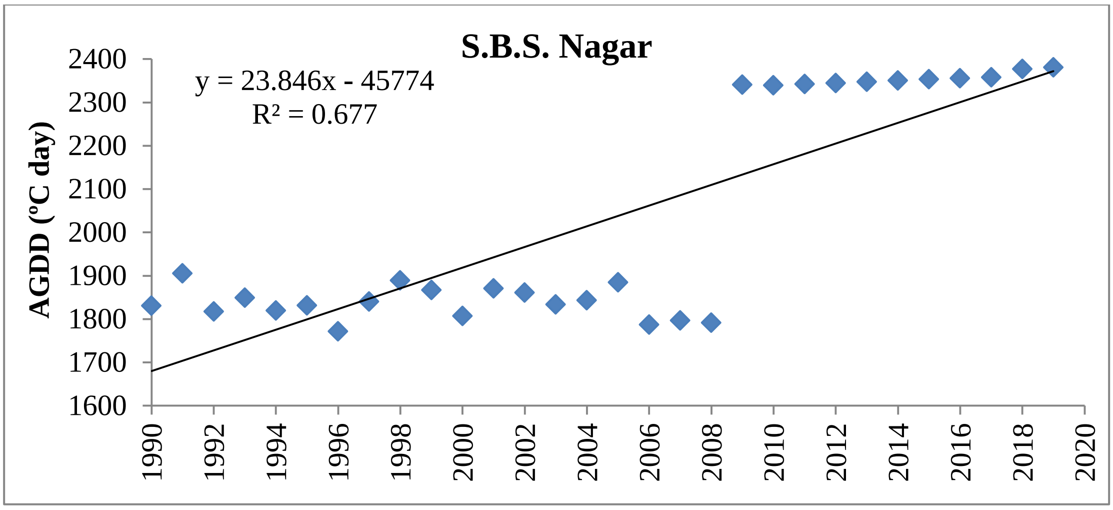


Fig. 4.8: Variability in annual AGDD from 1990 to 2019 at SBSN under transplanting window I

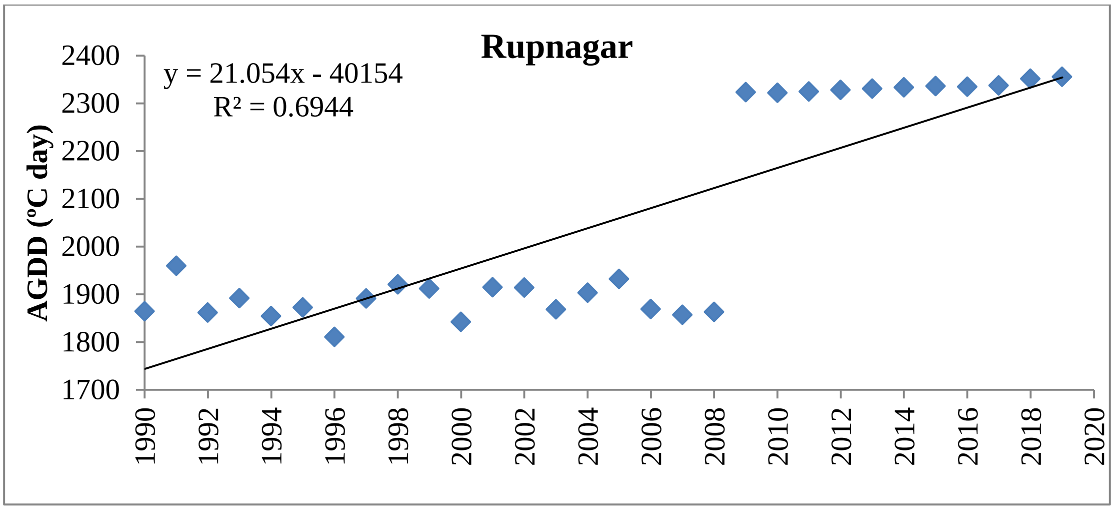


Fig. 4.9: Variability in annual AGDD from 1990 to 2019 at Rupnagar under transplanting window I

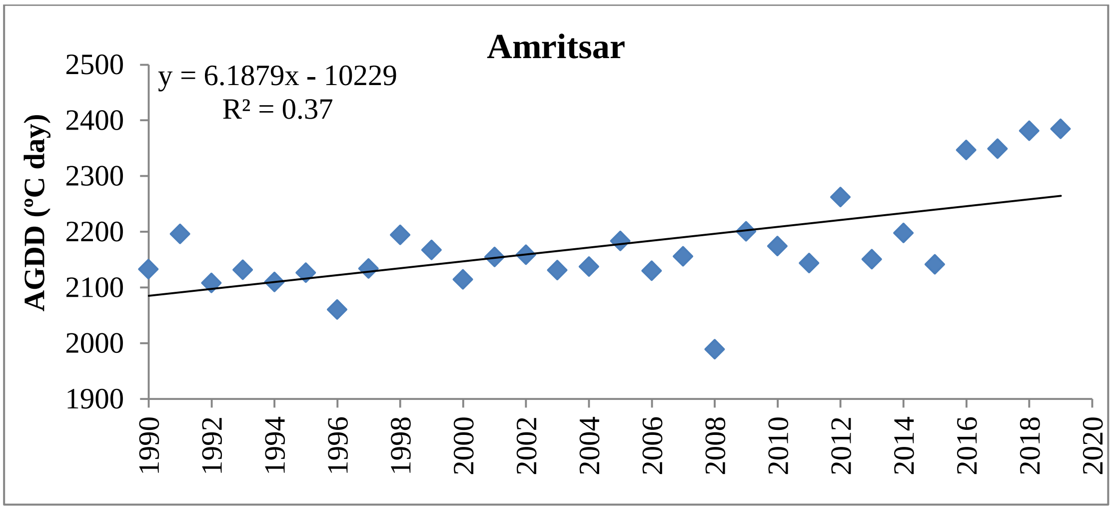


Fig. 4.10: Variability in annual AGDD from 1990 to 2019 at Amritsar under transplanting window I

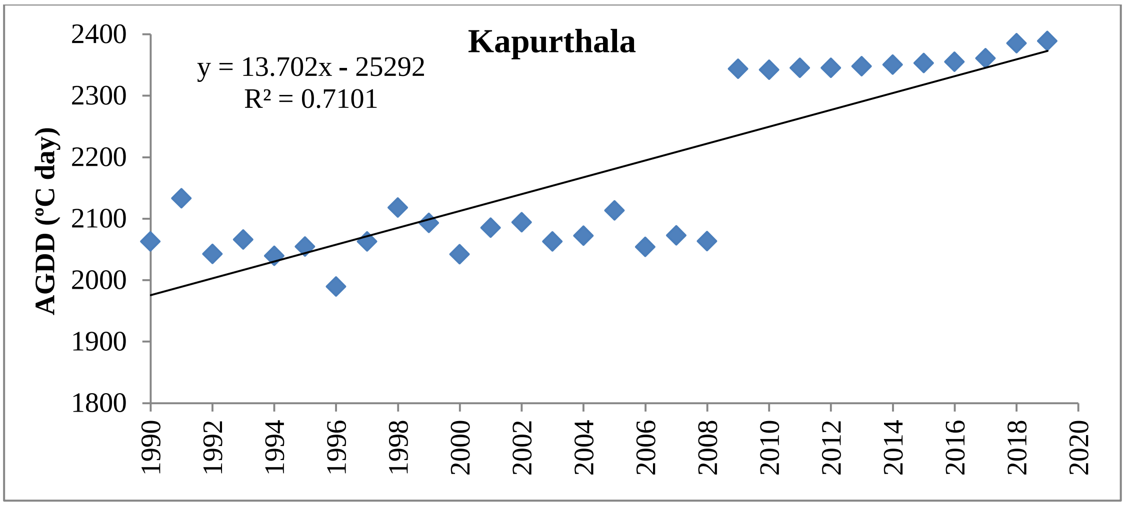


Fig. 4.11: Variability in annual AGDD from 1990 to 2019 at Kapurthala under transplanting window I

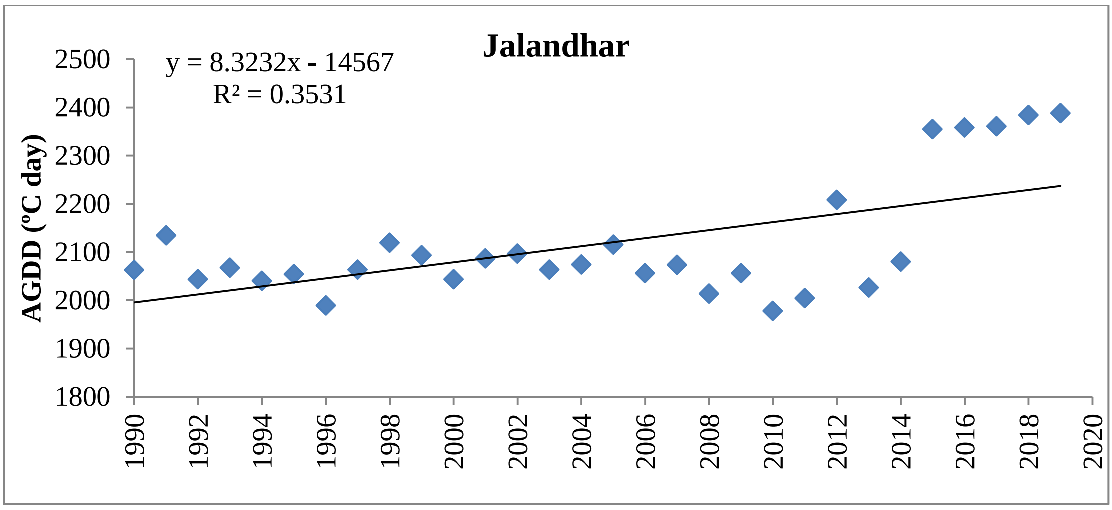


Fig. 4.12: Variability in annual AGDD from 1990 to 2019 at Jalandhar under transplanting window I

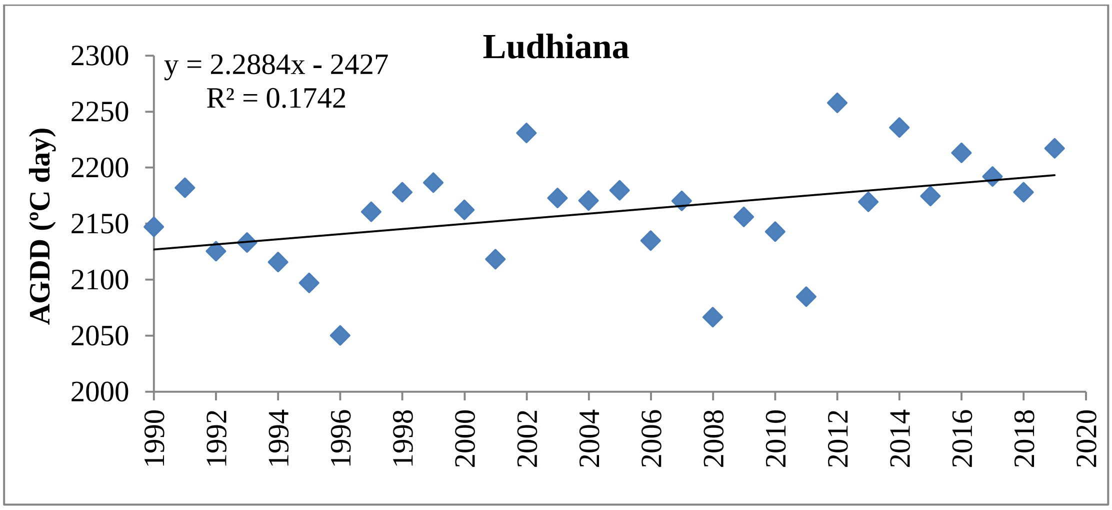


Fig. 4.13: Variability in annual AGDD from 1990 to 2019 at Ludhiana under transplanting window I

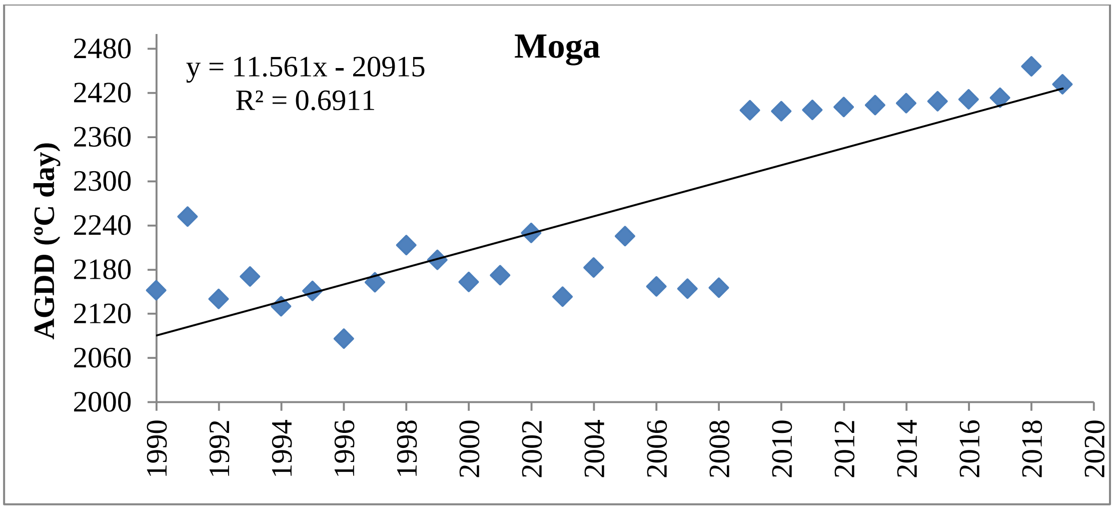


Fig. 4.14: Variability in annual AGDD from 1990 to 2019 at Moga under transplanting window I

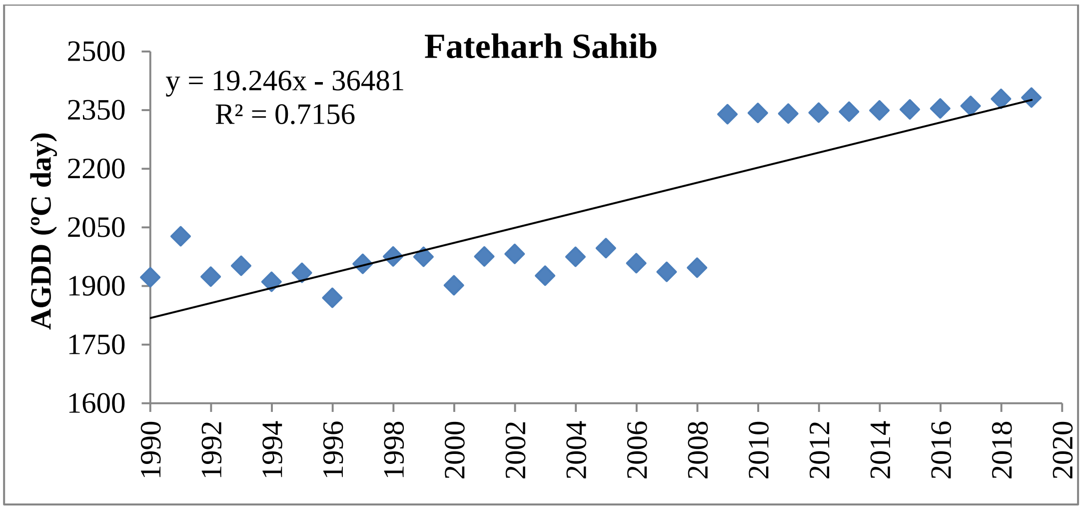


Fig. 4.15: Variability in annual AGDD from 1990 to 2019 at Fatehgarh Sahib under transplanting window I

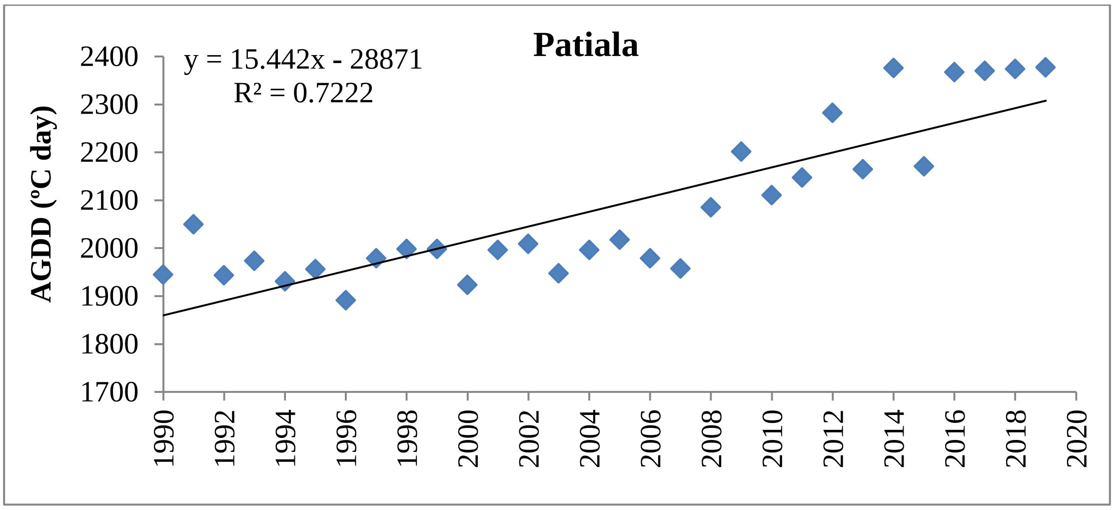


Fig. 4.16: Variability in annual AGDD from 1990 to 2019 at Patiala under transplanting window I

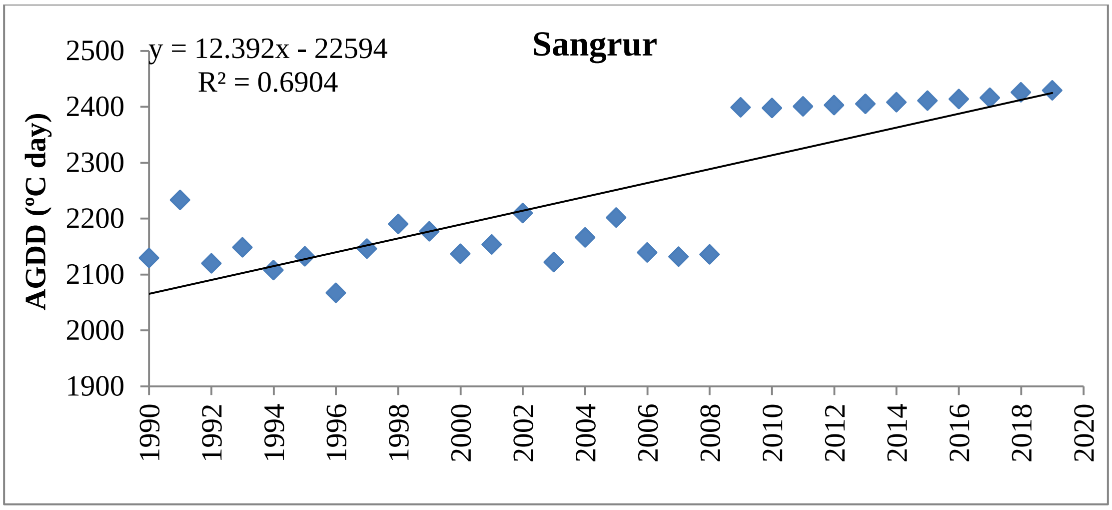


Fig. 4.17: Variability in annual AGDD from 1990 to 2019 at Sangrur under transplanting window I

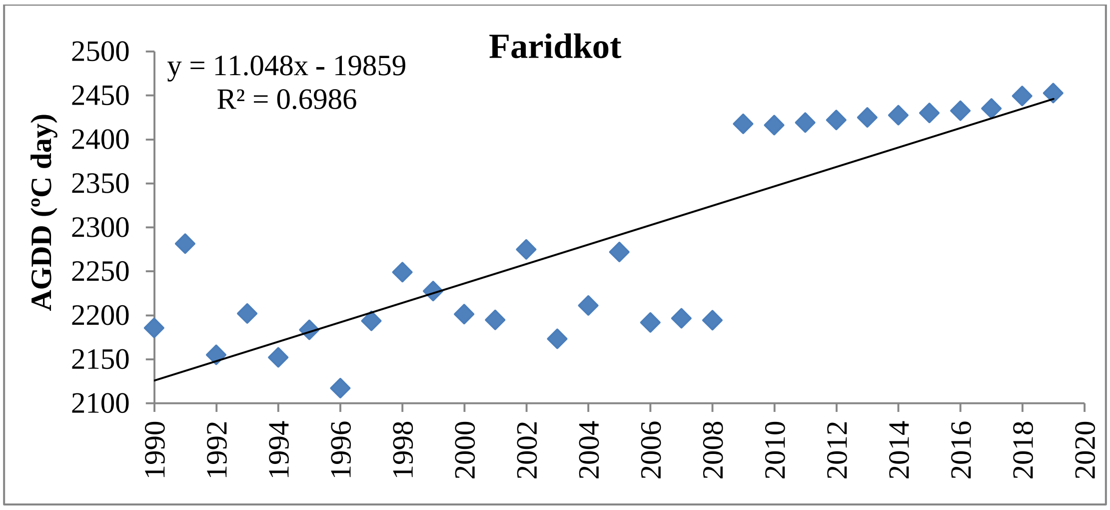


Fig. 4.18: Variability in annual AGDD from 1990 to 2019 at Faridkot under transplanting window I

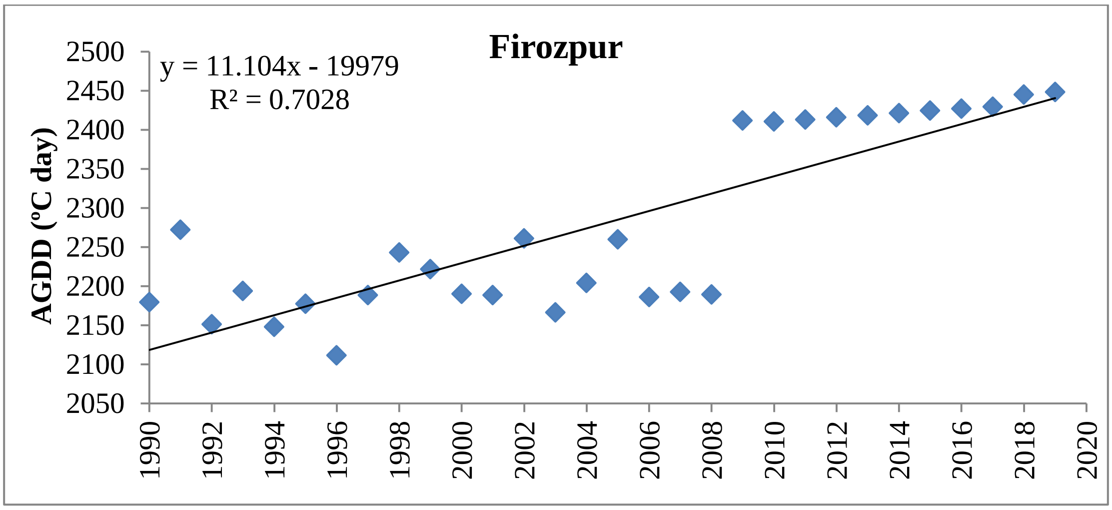


Fig. 4.19: Variability in annual AGDD from 1990 to 2019 at Firozpur under transplanting window I

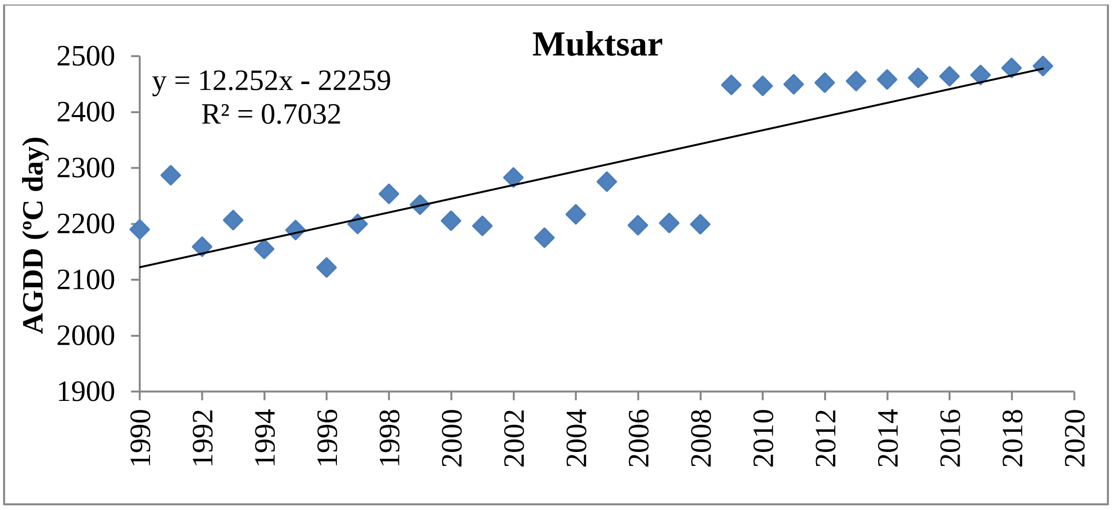


Fig. 4.20: Variability in annual AGDD from 1990 to 2019 at Muktsar under transplanting window I

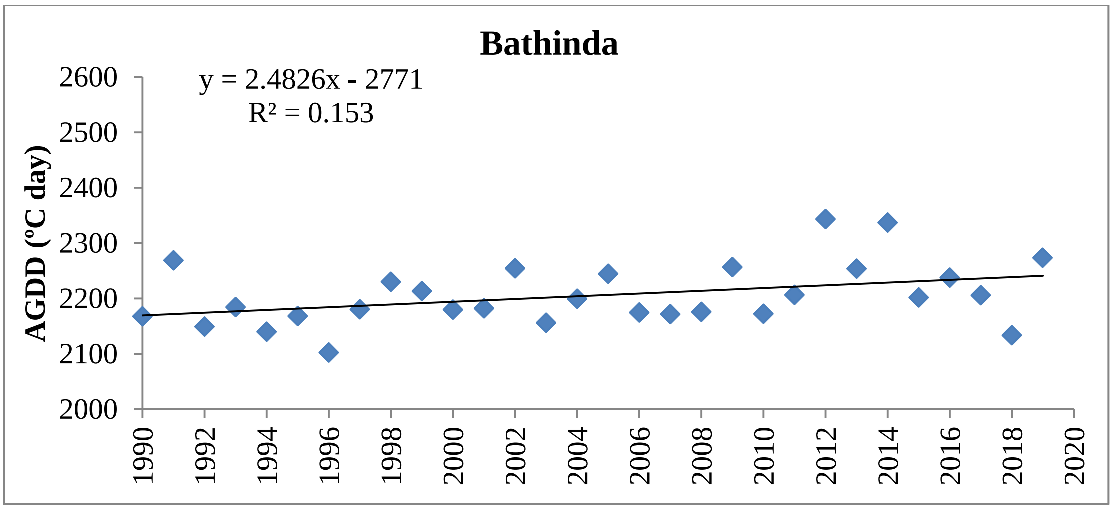


Fig. 4.21: Variability in annual AGDD from 1990 to 2019 at Bathinda under transplanting window I

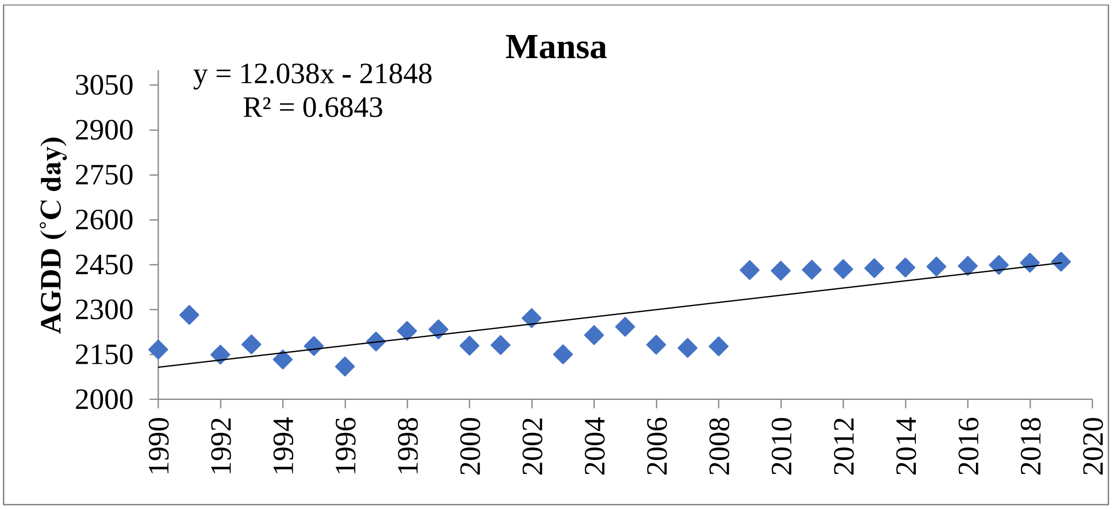


Fig. 4.22: Variability in annual AGDD from 1990 to 2019 at Mansa under transplanting window I

4.2.2 Trend analysis of accumulated growing degree days of rice under transplanting window II

The data from 1990-2019 was analyzed for trends (increasing or decreasing) in accumulated growing degree days (AGDD) under transplanting window II and presented in figures from 4.23 to 4.39. Variation in heat unit was observed during different time period. It was observed that there was increasing trend of accumulated growing degree days (AGDD) in all the districts except Ludhiana and Bathinda where no such prominent increasing trend was found. The R^2 value was highest at Gurdaspur (0.76) and lowest at Bathinda (0.21). Among all the districts the highest rate of increase in AGDD was found in S.B.S Nagar (22.22ºC day year^{-1}) followed by Rupnagar (19.59ºC day year^{-1}) and then Fatehgarh Sahib (17.94 ºC day year^{-1}) and lowest was for Ludhiana (2.49ºC day year^{-1}) followed by Bathinda (2.84ºC day year^{-1}). It was 13.58ºC day year^{-1} in Hoshiarpur, 6.02ºC day year^{-1} in Amritsar, 12.89ºC day year^{-1} in Kapurthala, 7.95ºC day year^{-1} in Jalandhar, 10.73ºC day year^{-1} in Moga, 14.72ºC day year^{-1} in Patiala, 11.47ºC day year^{-1} in Sangrur, 10.25ºC day year^{-1} in Faridkot, 10.29ºC day year^{-1} in Firozpur, 11.42ºC day year^{-1}in Muktsar, 11.15ºC day year^{-1} in Mansa.

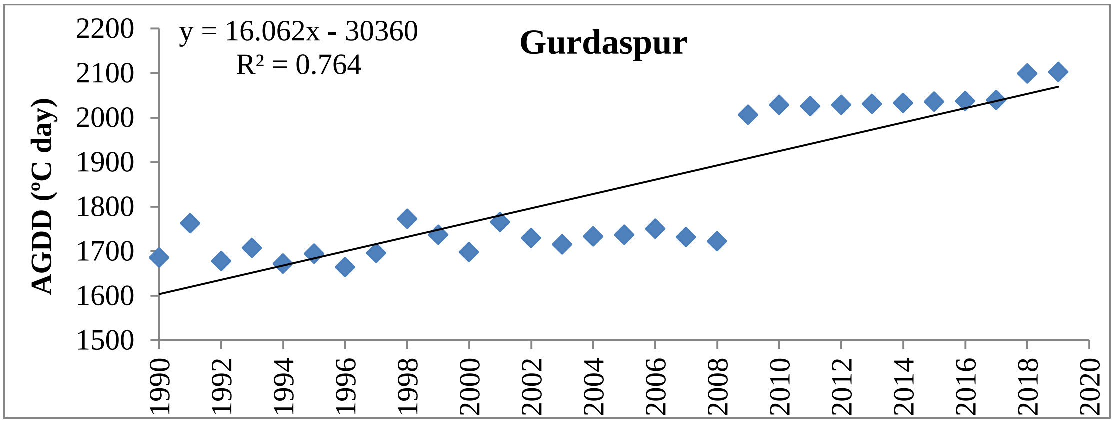


Fig. 4.23: Variability in annual AGDD from 1990 to 2019 at Gurdaspur under transplanting window II

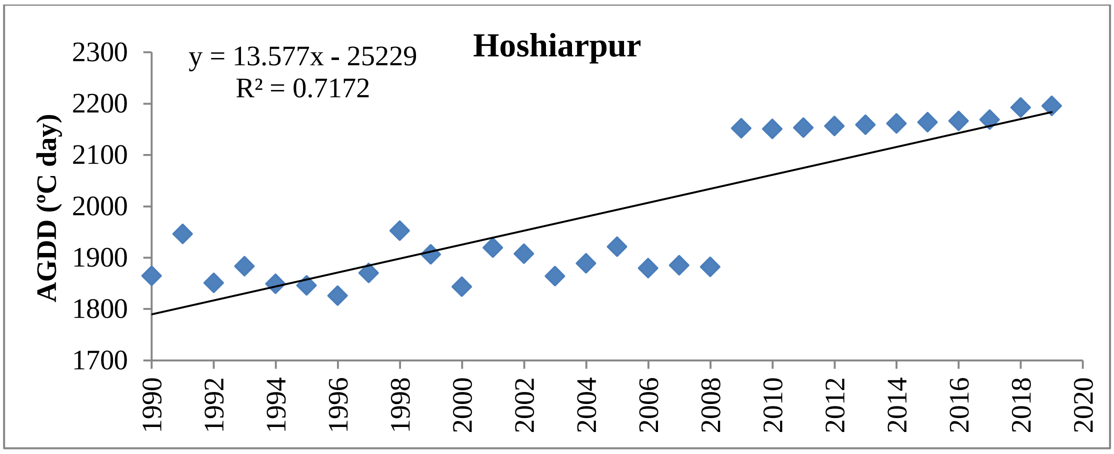


Fig. 4.24: Variability in annual AGDD from 1990 to 2019 at Hoshiarpur under transplanting window II

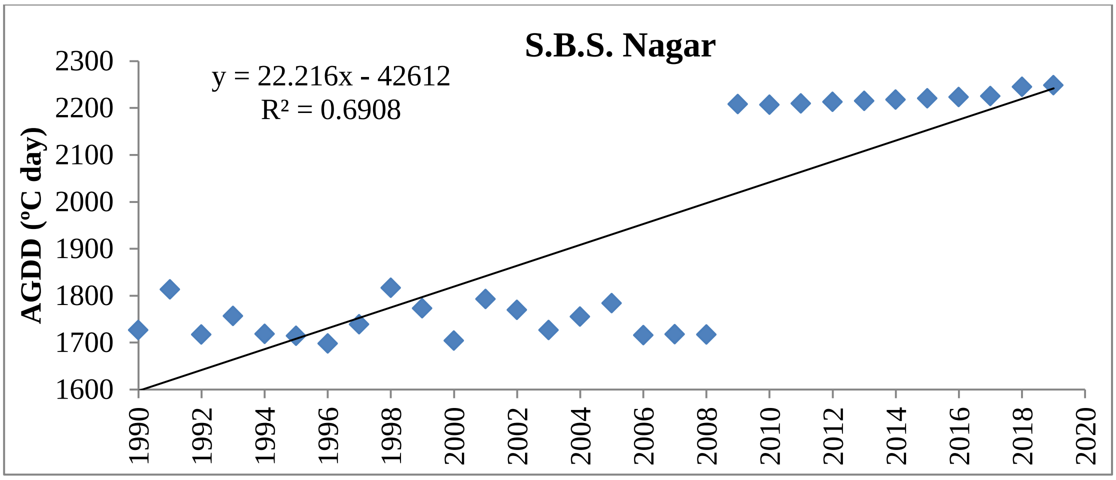


Fig. 4.25: Variability in annual AGDD from 1990 to 2019 at SBSN under transplanting window II

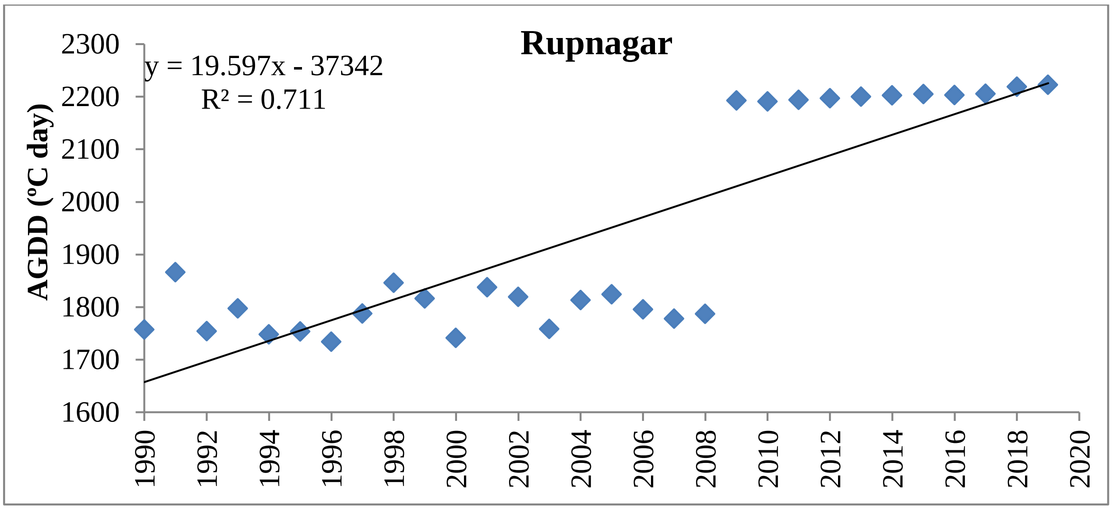


Fig. 4.26: Variability in annual AGDD from 1990 to 2019 at Rupnagar under transplanting window II

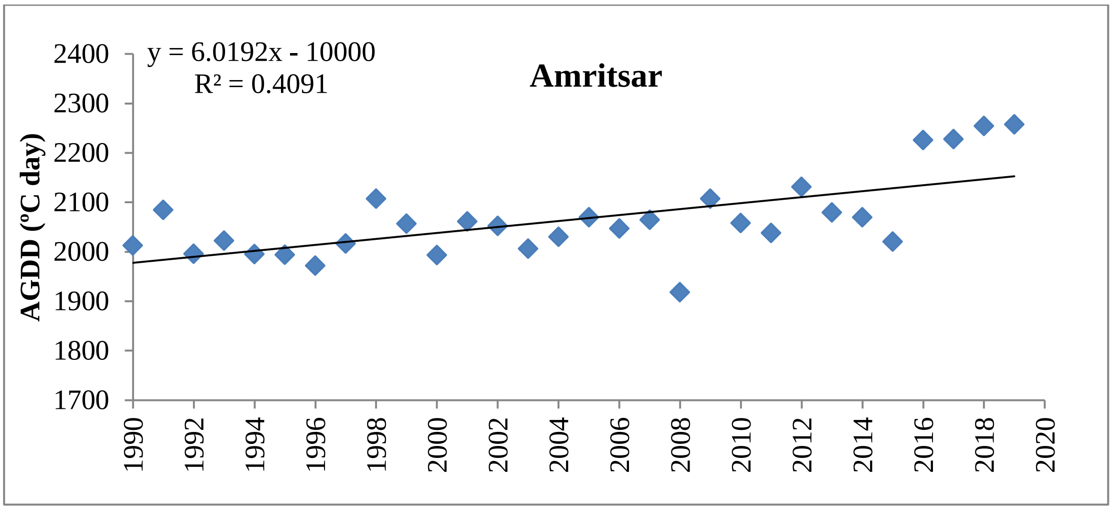


Fig. 4.27: Variability in annual AGDD from 1990 to 2019 at Amritsar under transplanting window II

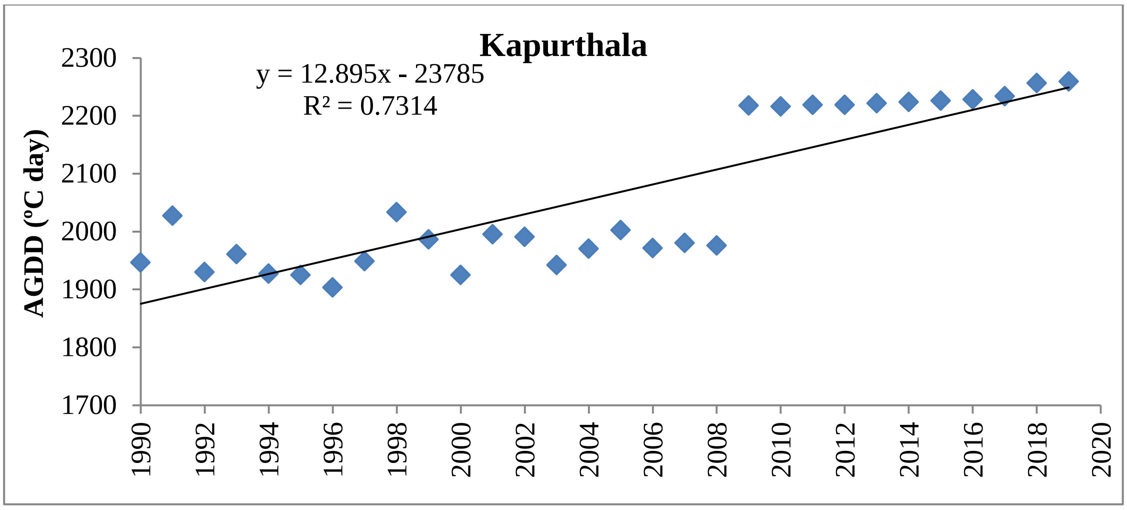


Fig. 4.28: **Variability in annual AGDD from 1990 to 2019 at Kapurthala under transplanting window II**

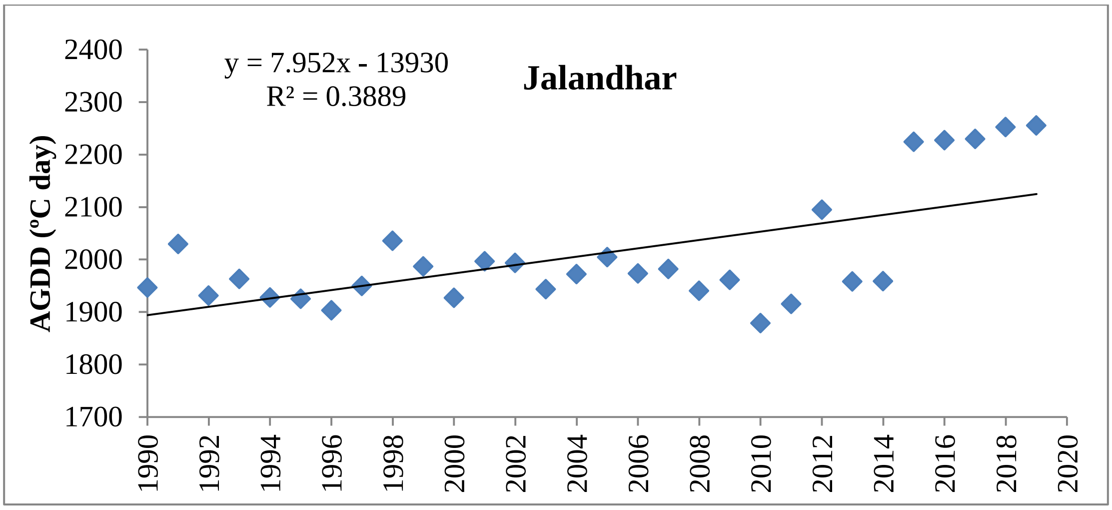


Fig. 4.29: **Variability in annual AGDD from 1990 to 2019 at Jalandhar under transplanting window II**

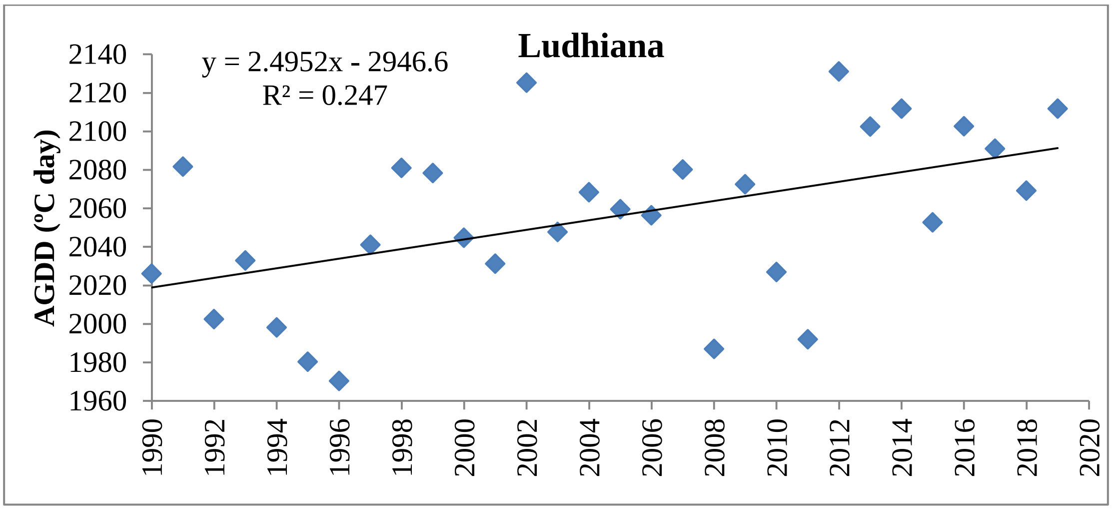


Fig. 4.30: **Variability in annual AGDD from 1990 to 2019 at Ludhaian under transplanting window II**

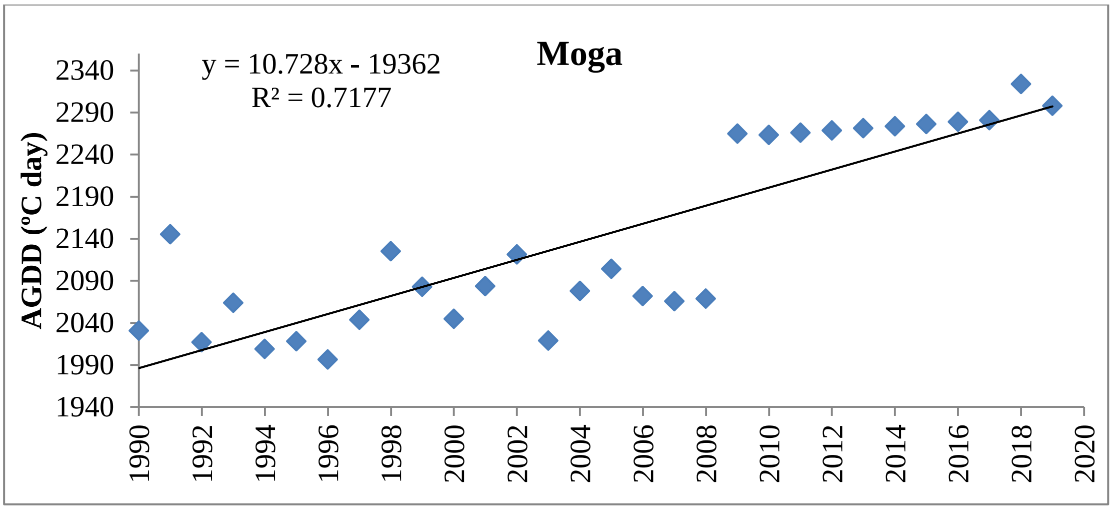


Fig. 4.31: **Variability in annual AGDD from 1990 to 2019 at Moga under transplanting window II**

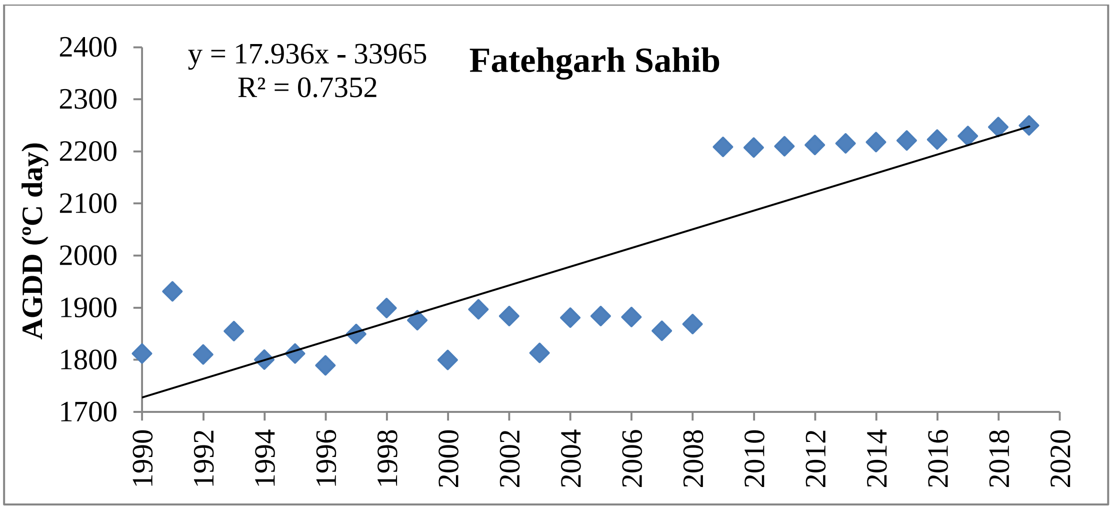


Fig. 4.32: **Variability in annual AGDD from 1990 to 2019 at Fatehgarh Sahib under transplanting window II**

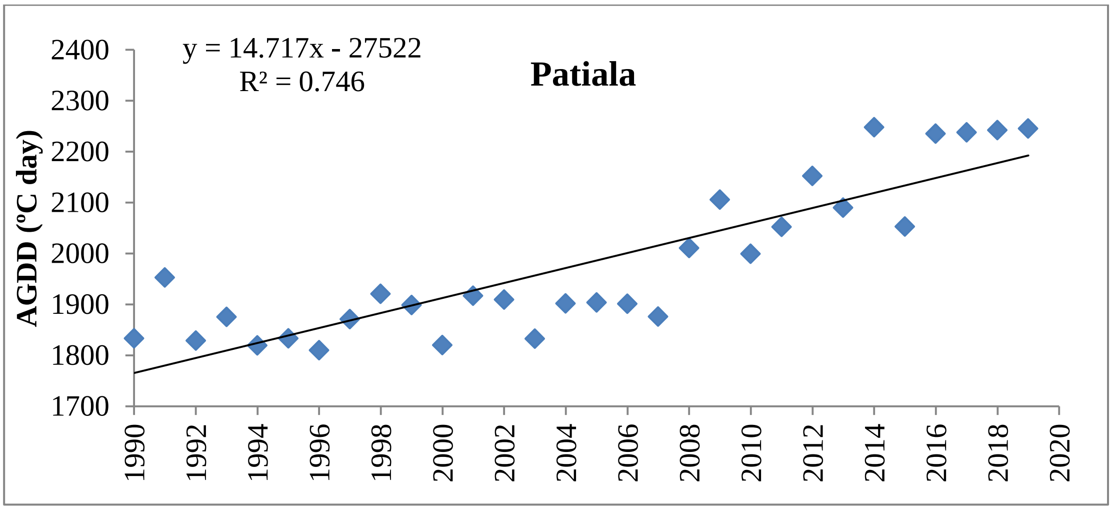


Fig. 4.33: **Variability in annual AGDD from 1990 to 2019 at Patiala under transplanting window II**

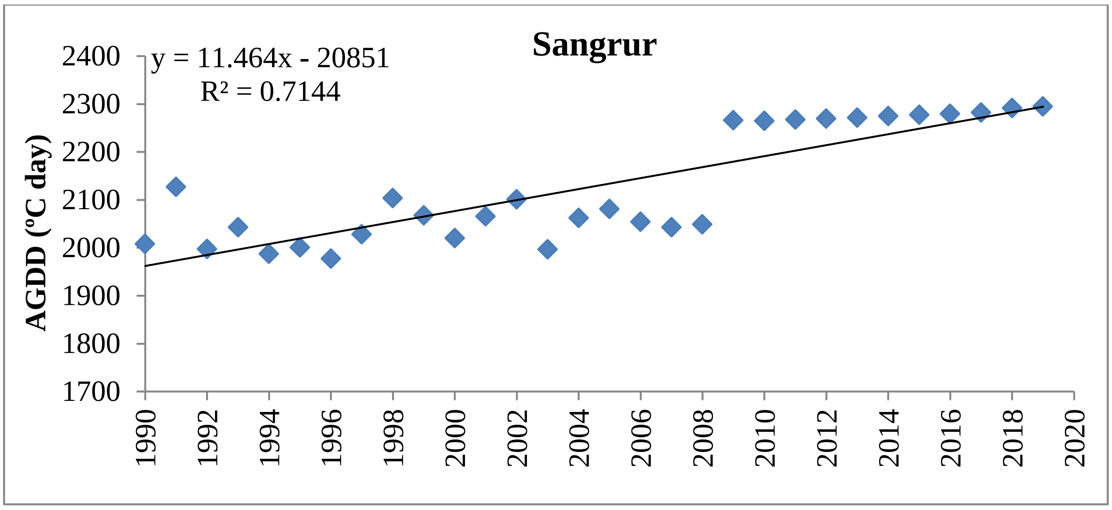


Fig. 4.34: Variability in annual AGDD from 1990 to 2019 at Sangrur under transplanting window II

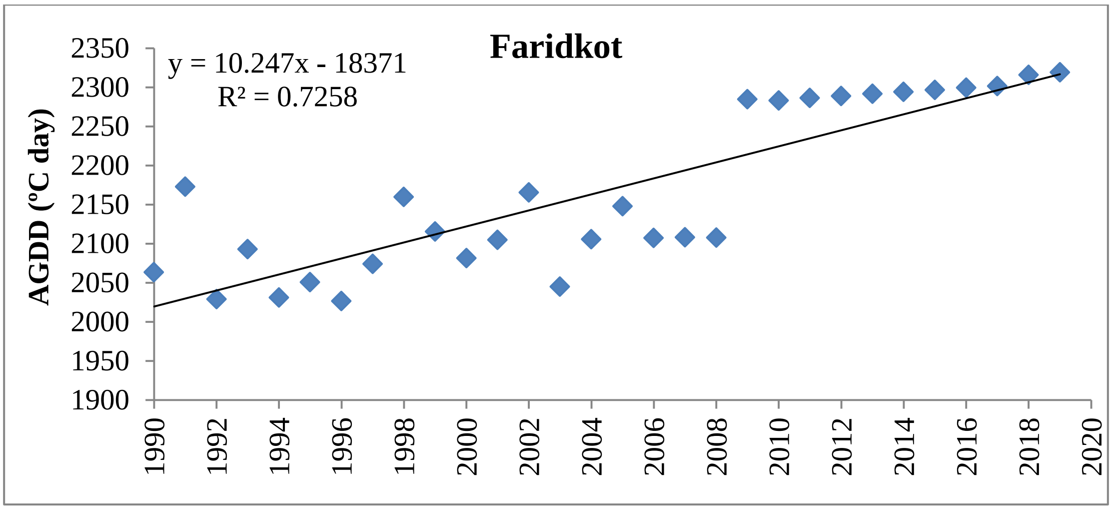


Fig. 4.35: Variability in annual AGDD from 1990 to 2019 at Faridkot under transplanting window II

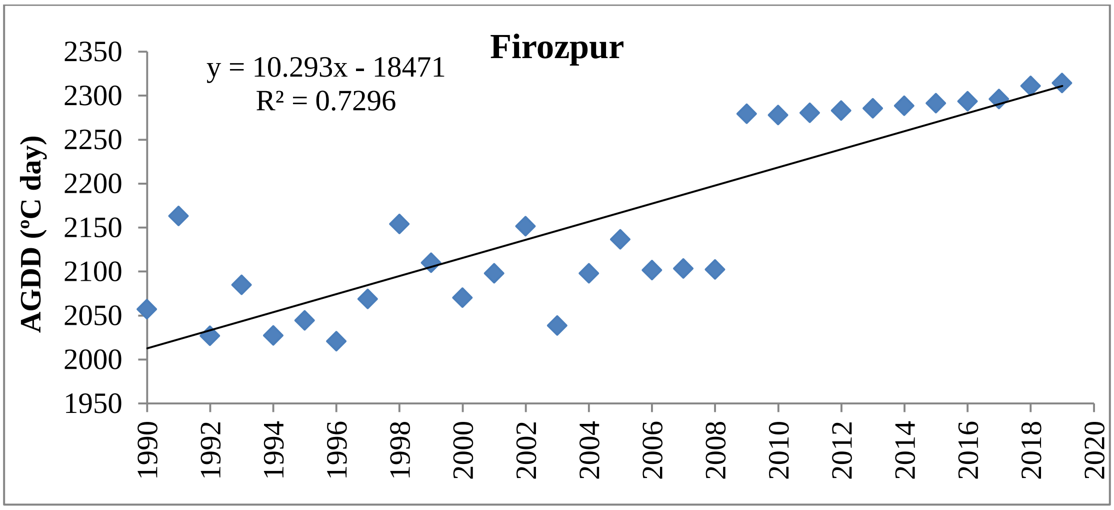


Fig. 4.36: Variability in annual AGDD from 1990 to 2019 at Firozpur under transplanting window II

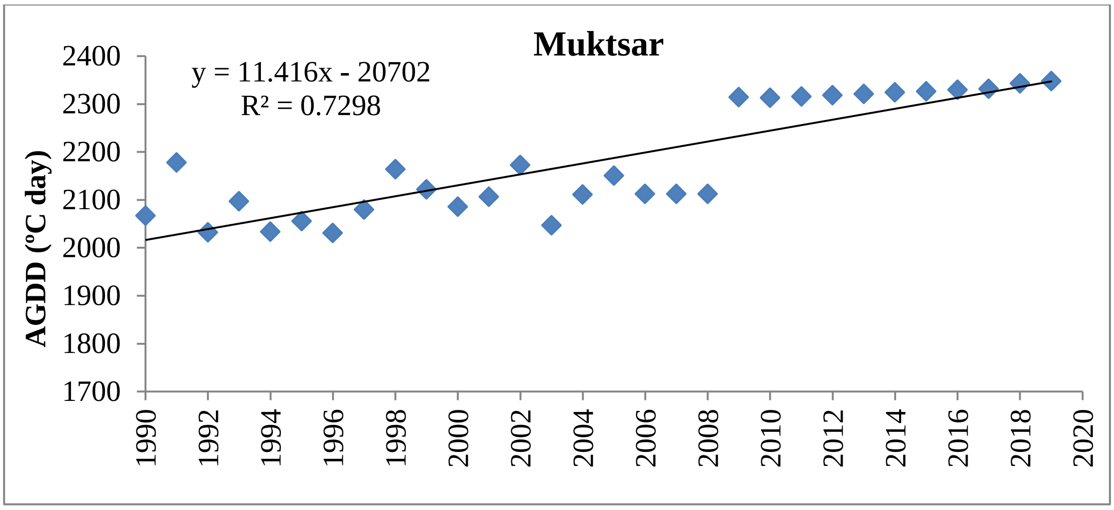


Fig. 4.37: **Variability in annual AGDD from 1990 to 2019 at Muktsar under transplanting window II**

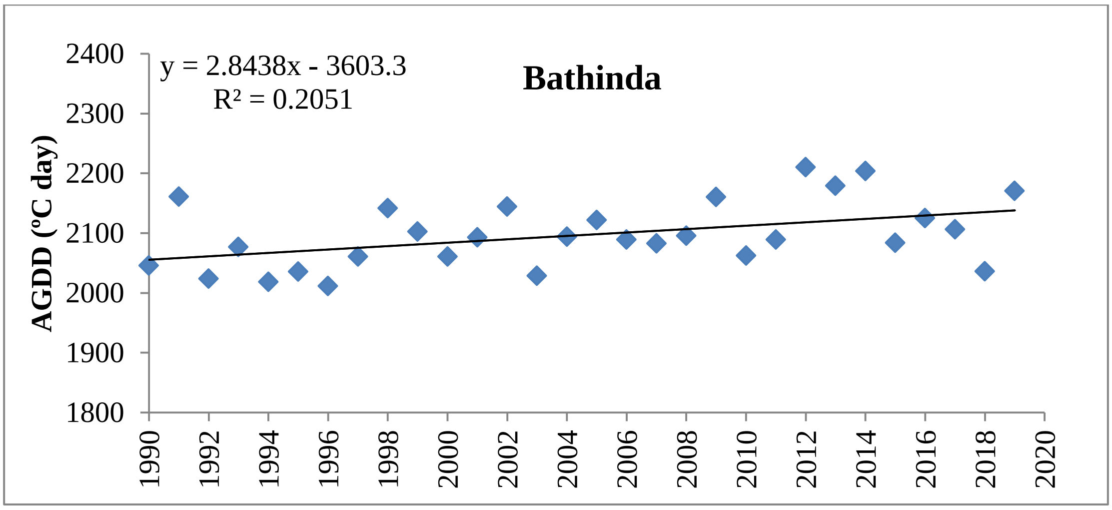


Fig. 4.38: **Variability in annual AGDD from 1990 to 2019 at Bathinda under transplanting window II**

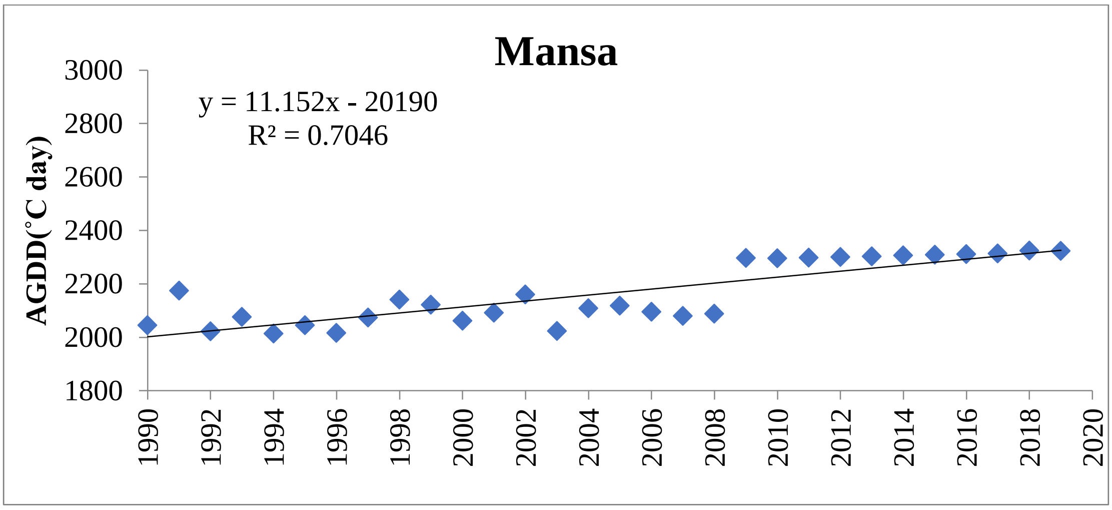


Fig. 4.39: **Variability in annual AGDD from 1990 to 2019 at Mansa under transplanting window II**

4.2.3 Trend analysis of accumulated growing degree days of rice under transplanting window III

The data from 1990-2019 was analyzed for trends (increasing or decreasing) in accumulated growing degree days (AGDD) under transplanting window III and presented in figures from 4.40 to 4.56. Variation in heat unit was observed during different time period. It was observed that there was increasing trend of accumulated growing degree days (AGDD) in all the districts except Ludhiana and Bathinda where no such prominent increasing trend was found. The R^2 value was highest at Patiala (0.77) and lowest at Bathinda (0.27). Among all the districts the highest rate of increase in AGDD was found in S.B.S. Nagar (21.89°C day year^{-1}) followed by Rupnagar (19.25°C day year^{-1}) and then Fatehgarh Sahib (17.68°C day year^{-1}) and lowest was for Ludhiana (2.57°C day year^{-1}) followed by Bathinda (3.05°C day year^{-1}). It was 13.47°C day year^{-1} in Hoshiarpur, 6.21°C day year^{-1} in Amritsar, 12.64°C day year^{-1} in Kapurthala, 7.93°C day year^{-1} in Jalandhar, 10.68°C day year^{-1} in Moga, 14.41°C day year^{-1} in Patiala, 11.60°C day year^{-1} in Sangrur, 10.23°C day year^{-1} in Faridkot, 10.33°C day year^{-1} in Firozpur, 11.33°C day year^{-1} in Muktsar, 11.26°C day year^{-1} in Mansa.

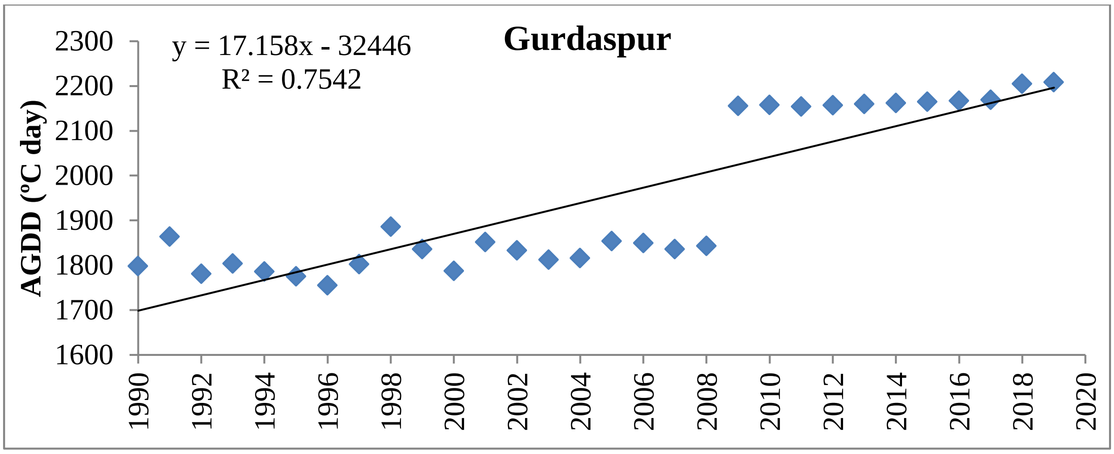


Fig. 4.40: Variability in annual AGDD from 1990 to 2019 at Gurdaspur under transplanting window III

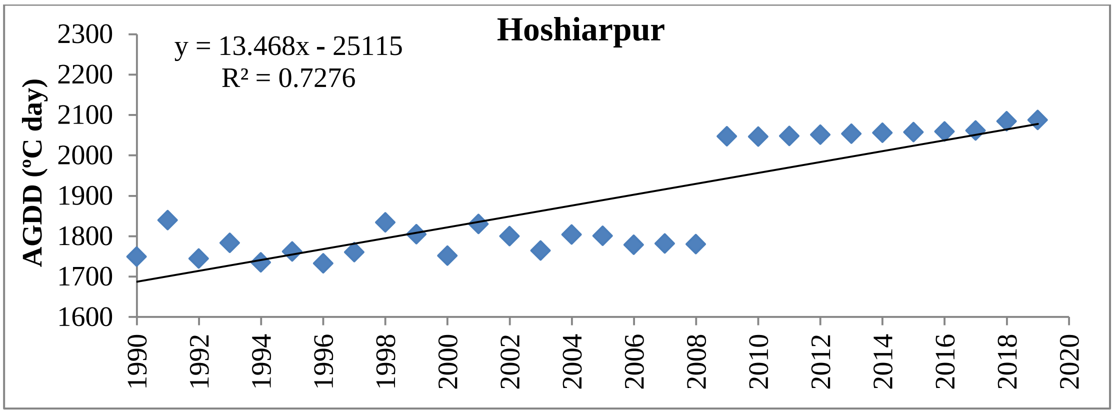


Fig. 4.41: Variability in annual AGDD from 1990 to 2019 at Hoshiarpur under transplanting window III

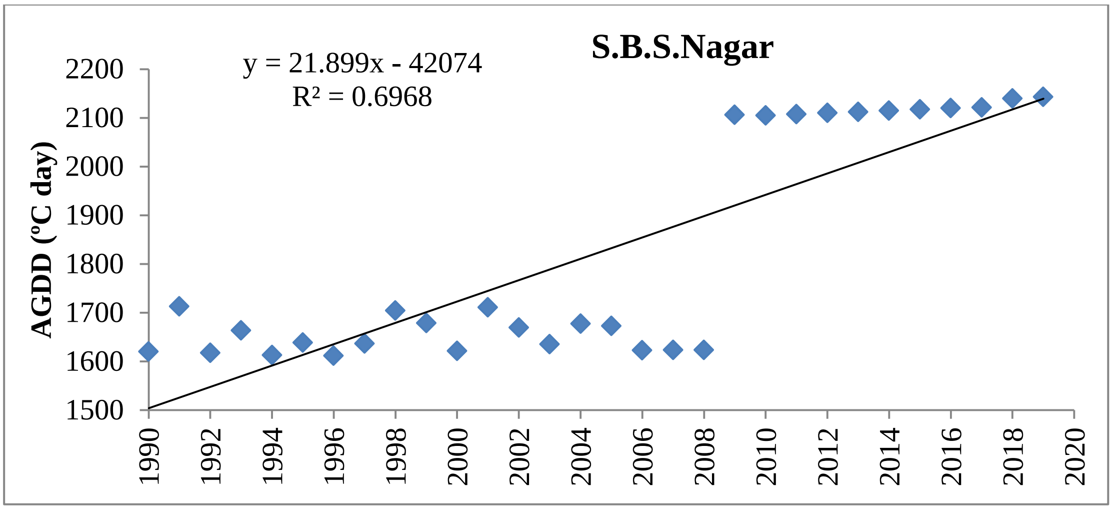


Fig. 4.42: Variability in annual AGDD from 1990 to 2019 at SBSN under transplanting window III

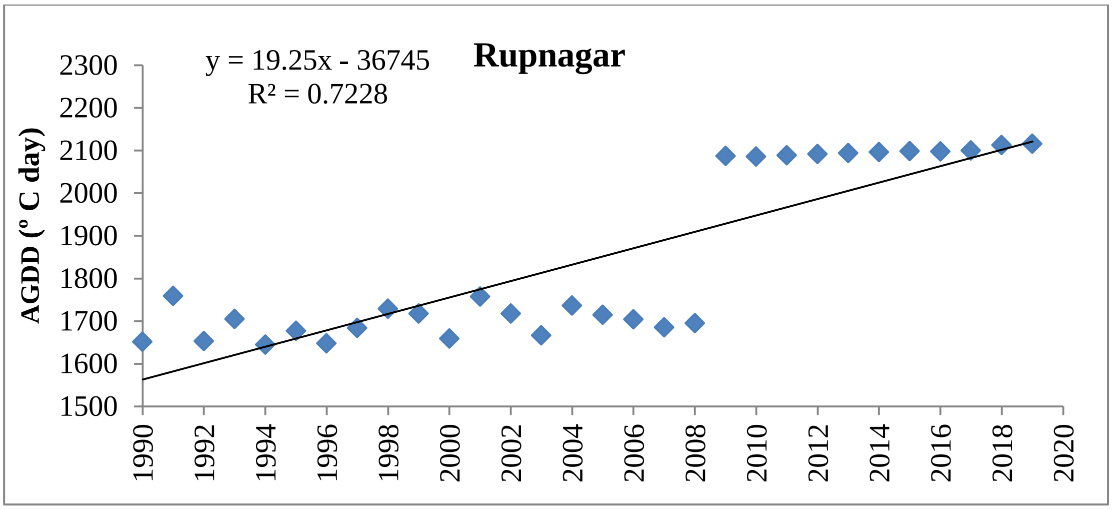


Fig. 4.43: Variability in annual AGDD from 1990 to 2019 at Rupnagar under transplanting window III

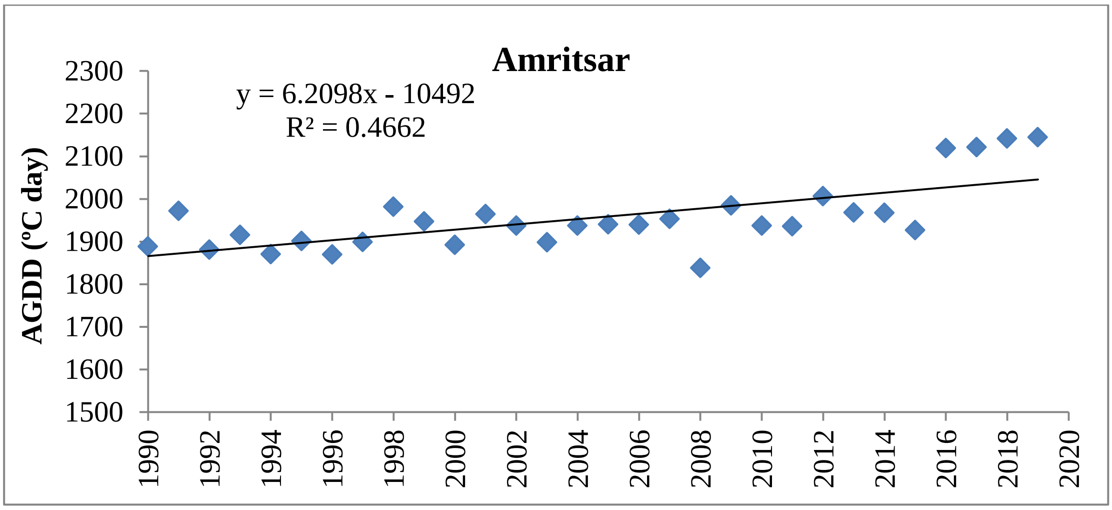


Fig. 4.44: Variability in annual AGDD from 1990 to 2019 at Amritsar under transplanting window III

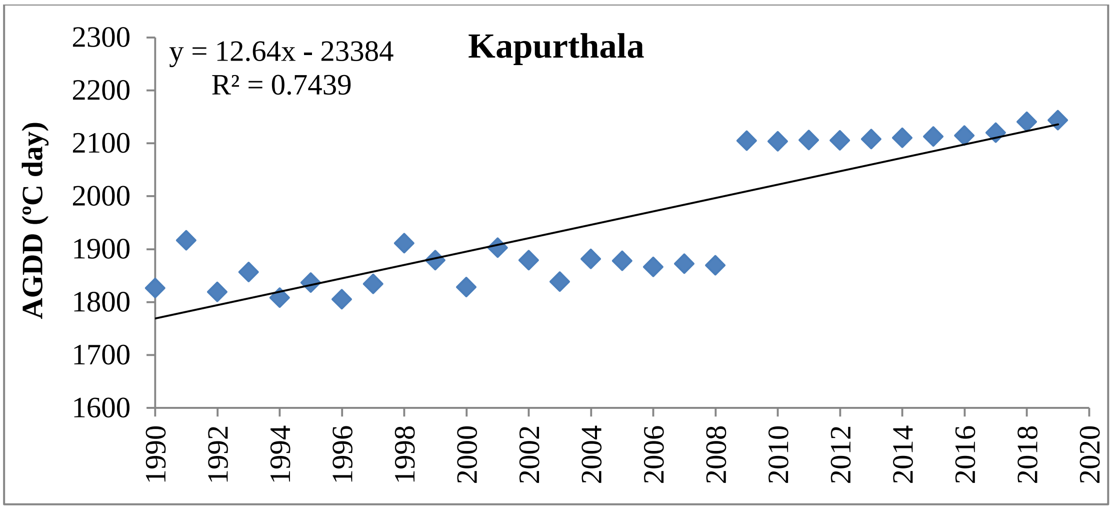


Fig. 4.45: Variability in annual AGDD from 1990 to 2019 at Kapurthala under transplanting window III

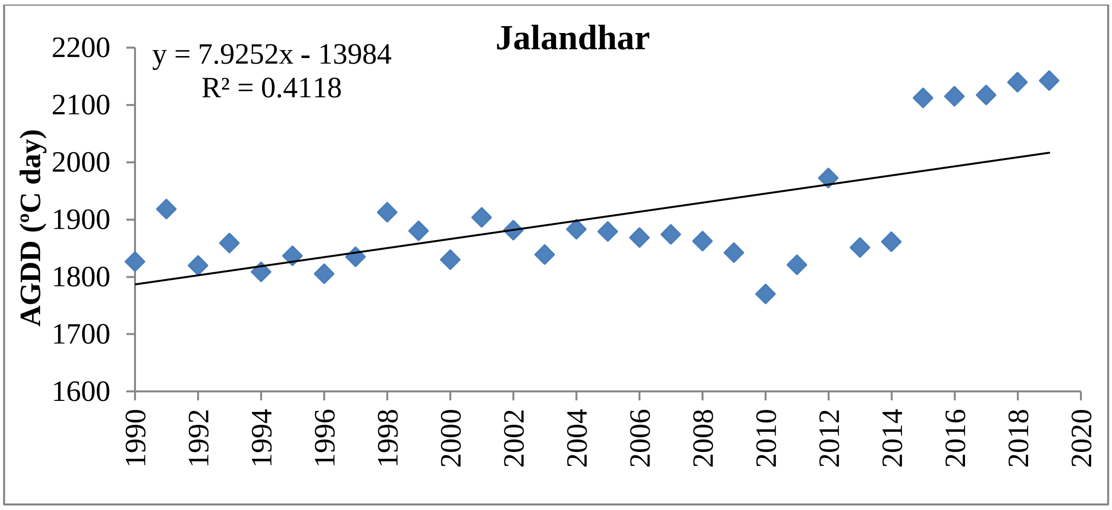


Fig. 4.46: Variability in annual AGDD from 1990 to 2019 at Jalandhar under transplanting window III

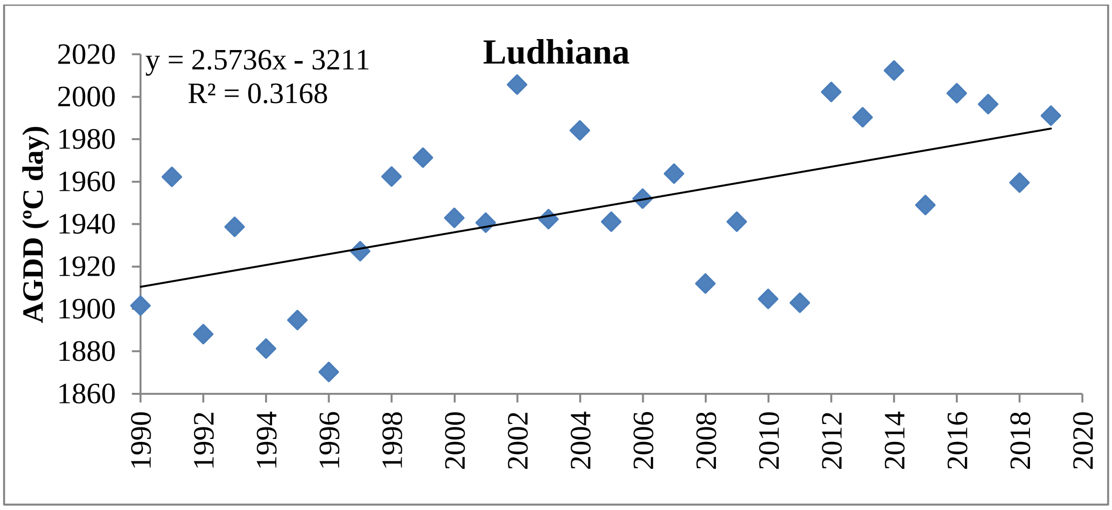


Fig. 4.47: Variability in annual AGDD from 1990 to 2019 at Ludhiana under transplanting window III

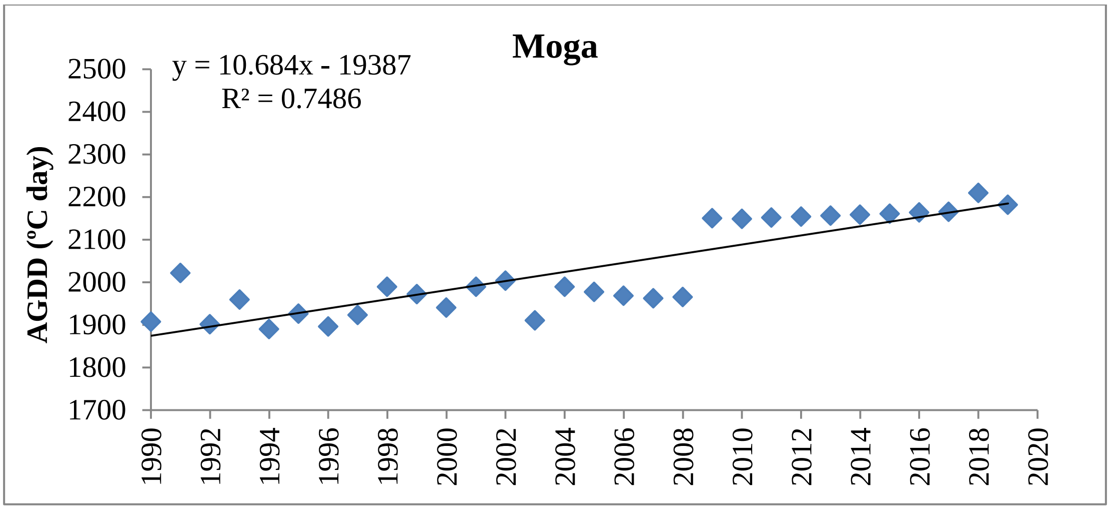


Fig. 4.48: Variability in annual AGDD from 1990 to 2019 at Moga under transplanting window III

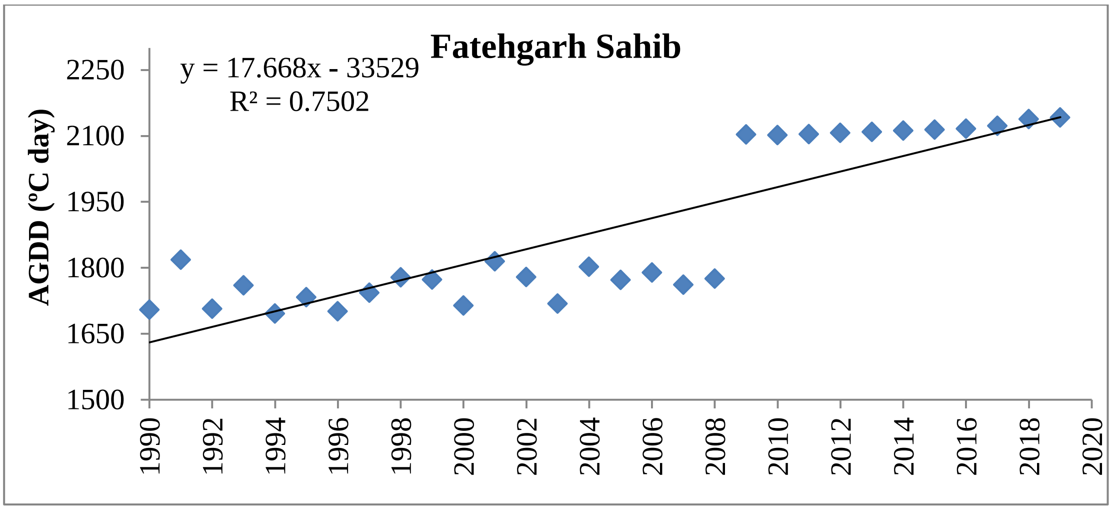


Fig. 4.49: Variability in annual AGDD from 1990 to 2019 at Fatehgarh Sahib under transplanting window III

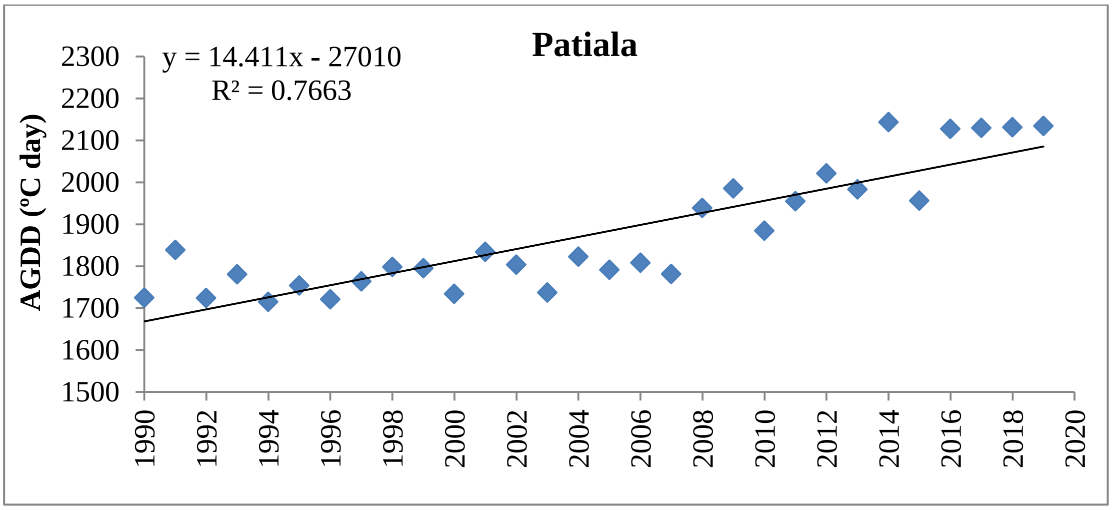


Fig. 4.50: Variability in annual AGDD from 1990 to 2019 at Patiala under transplanting window III

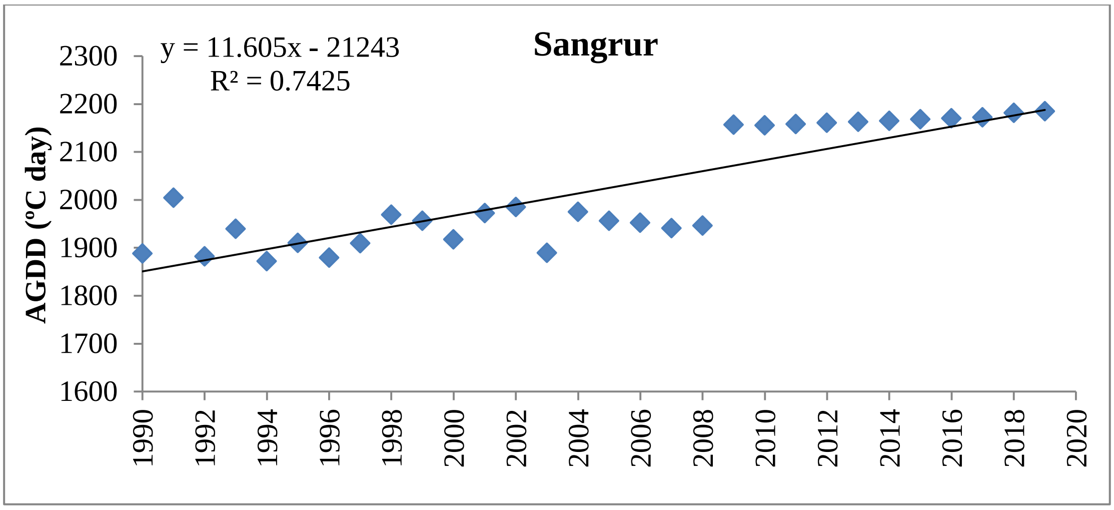


Fig. 4.51: Variability in annual AGDD from 1990 to 2019 at Sangrur under transplanting window III

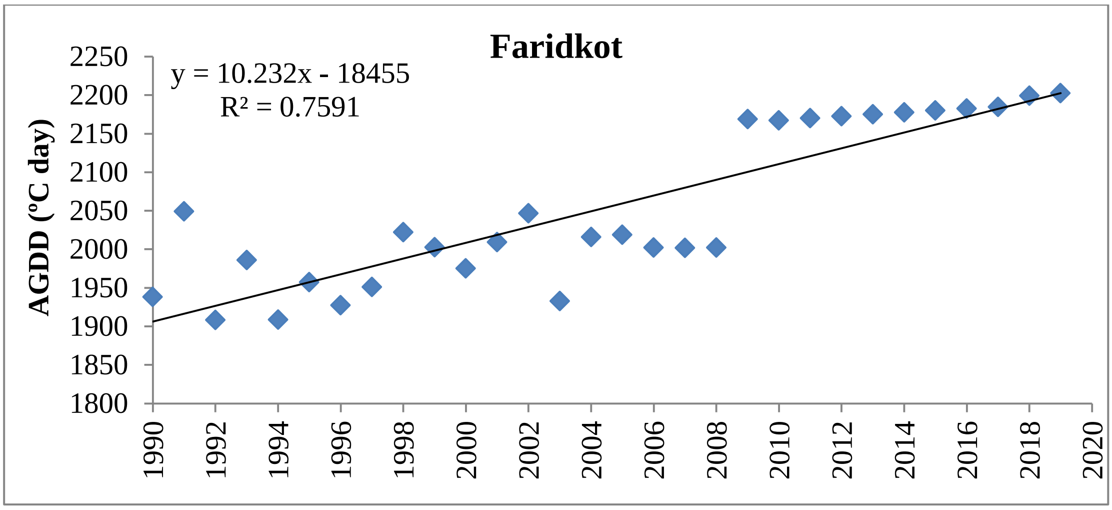


Fig. 4.52: Variability in annual AGDD from 1990 to 2019 at Faridkot under transplanting window III

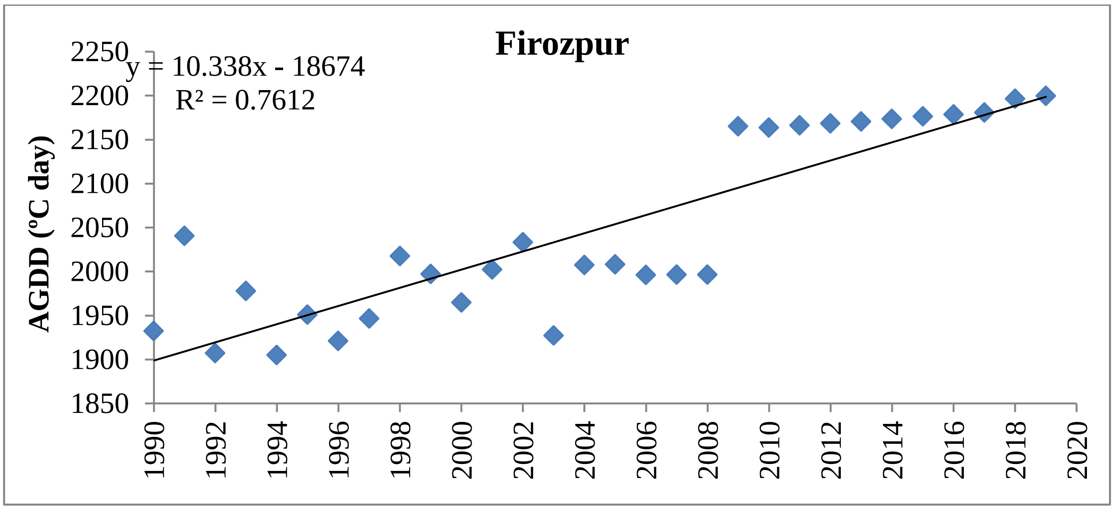


Fig. 4.53: Variability in annual AGDD from 1990 to 2019 at Firozpur under transplanting window III

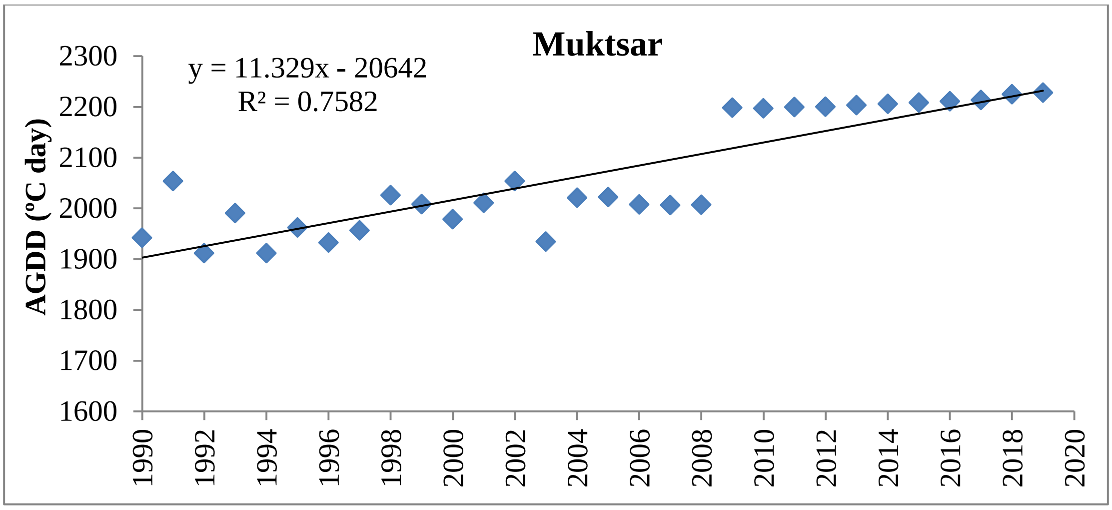


Fig. 4.54: Variability in annual AGDD from 1990 to 2019 at Muktsar under transplanting window III

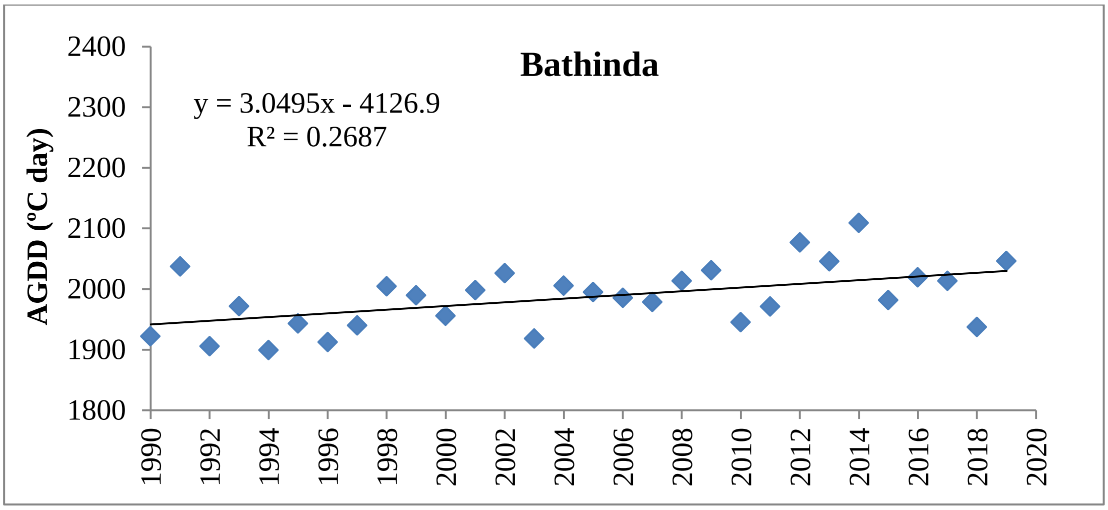


Fig. 4.55: Variability in annual AGDD from 1990 to 2019 at Bathinda under transplanting window III

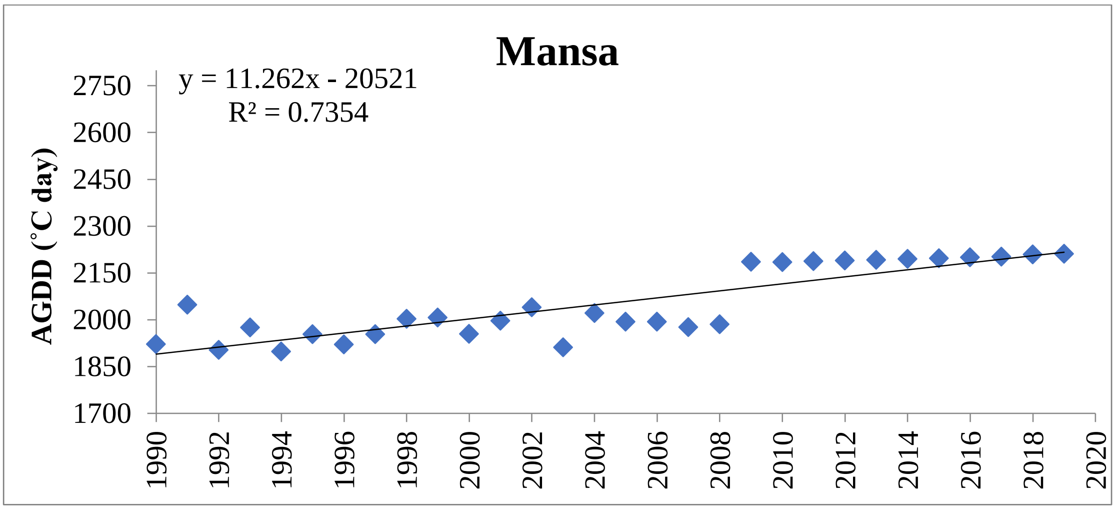


Fig. 4.56: Variability in annual AGDD from 1990 to 2019 at Mansaunder transplanting window III

4.2.4 Variability of accumulated growing degree days at different phenological stages of rice during different pentads under different transplanting windows

For depicting the spatio-temporal variability in thermal requirements of rice under staggered transplanting, we divide the whole state into three agroclimatic regions (Kaur 2016):

1. North-East Region
2. Central Region
3. South-West Region

In North east region under transplanting window I to complete different phenological stages namely Maximum tillering, Booting, 50% Panicle Initiation, Anthesis, Grain filling and physiological maturity maximum heat units were accumulated by rice in district Hoshiarpur at all the stages. This maximum accumulation of heat unit was obsereved from the period P1 (1990-1994) to P4 (2005-2009). During the next two pentads P5 and P6 the pattern of heat unit accumulation shifted to S.B.S.Nagar. While analyzing the minimum accumulation of GDD, the pattern was reversed which means that during the period P1 (1990-1994) to P4 (2005-2009), S.B.S. Nagar accumulated lowest heat units and from P5 (2010-2014) to P6 (2015-2019) by Hoshiarpur district to complete phenological stages. For the next two transplanting windows the pattern of heat accumulation to complete different phenological stages remained the same for the same two districts and for the same period.

In the central region under transplanting window I to complete different phenological stages the crop at district Moga had accumulated maximum GDD during all the pentads . The lowest GDD was accumulated at Fatehgarh Sahib from P1 (1990-1994) to P4 (2005-2009) at Jalandhar in P5 (2010-2014) and at Ludhiana in P6 (2015-2019).This same pattern of heat unit accumulation was observed in transplanting window II and III.

In the south west region under transplanting window I to complete phenological stages the rice crop at Muktsar district accumulated maximum heat unit during during all the pentads. The lowest heat units accumulation was in Bathinda from P1 to P6. This same pattern of GDD accumulation was observed in II and III transplanting windows.

Table 4.6: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Gurdaspur

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	18.3	20.5	19.7	668.8	739.5	720.9	1056.8	1054.9	1087.7	1317.5	1337.7	1275.6
1995-1999	18.4	18.2	19.1	666.8	743.8	728.9	1054.5	1053.7	1090.3	1313.4	1326.3	1274.1
2000-2004	20.1	19.4	19.6	666.7	743.8	732.8	1059.1	1061.4	1104.7	1324.9	1343.1	1294.7
2005-2009	21.0	21.3	19.9	687.9	772.6	749.5	1094.6	1110.5	1146.4	1382.5	1404.4	1340.1
2010-2014	25.6	25.5	25.0	816.1	873.8	840.8	1255.6	1250.0	1283.2	1586.8	1569.8	1505.0
2015-2019	25.9	25.7	26.0	824.8	883.1	849.5	1268.7	1263.5	1296.8	1603.2	1586.5	1521.6

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**
1990-1994	1370.0	1372.3	1307.3	1674.4	1627.6	1627.6	1906.7	1806.0	1806.0
1995-1999	1365.0	1360.0	1306.7	1663.0	1622.1	1622.1	1905.0	1810.4	1810.4
2000-2004	1376.2	1377.7	1328.1	1685.6	1640.1	1640.1	1918.4	1819.6	1819.6
2005-2009	1438.0	1438.3	1374.7	1752.1	1711.7	1711.7	2001.7	1907.2	1907.2
2010-2014	1644.8	1610.0	1540.4	1993.2	1913.6	1913.6	2289.8	2157.8	2157.8
2015-2019	1661.6	1627.5	1556.7	2014.9	1935.1	1935.1	2315.8	2182.3	2182.3

Table 4.7: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Hoshiarpur

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	19.5	21.4	20.4	698.2	1094.6	747.5	1099.3	1094.6	1127.2	1369.6	1422.6	1321.7
1995-1999	19.5	19.1	20.0	694.3	1090.5	753.5	1094.8	1090.5	1126.6	1361.7	1407.8	1317.6
2000-2004	21.1	20.2	20.3	690.3	1095.5	756.3	1095.2	1095.5	1139.5	1369.0	1422.3	1336.1
2005-2009	21.8	22.0	19.7	704.7	1127.1	762.7	1116.7	1127.1	1160.4	1404.8	1458.6	1359.7
2010-2014	25.4	25.8	21.3	809.4	1242.3	835.6	1248.4	1242.3	1279.6	1580.3	1606.4	1502.1
2015-2019	25.6	26.1	21.6	818.1	1253.5	843.4	1260.6	1253.5	1290.4	1594.4	1620.9	1515.3

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	I	II	III	I	II	III	I	II	III
1990-1994	1423.9	1422.6	1354.9	1739.2	1690.1	1604.0	1984.0	1878.4	1769.8
1995-1999	1415.1	1407.8	1351.6	1725.3	1681.6	1605.6	1979.3	1879.9	1778.2
2000-2004	1422.0	1422.3	1370.8	1742.1	1694.9	1620.5	1986.0	1884.2	1789.7
2005-2009	1460.7	1458.6	1395.6	1783.4	1740.7	1653.5	2040.6	1943.6	1837.3
2010-2014	1640.1	1606.4	1540.8	1990.3	1912.2	1826.3	2284.9	2155.6	2050.2
2015-2019	1654.8	1620.9	1554.4	2009.0	1930.7	1843.9	2307.4	2177.0	2069.4

Table 4. 8: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in S.B.S Nagar

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	18.0	19.9	19.0	649.3	715.9	697.2	1023.6	1020.6	1051.6	1276.2	1292.9	1231.8
1995-1999	17.8	17.6	18.6	644.3	717.9	702.8	1018.7	1016.1	1050.4	1267.3	1278.8	1227.5
2000-2004	19.4	18.6	18.9	639.2	714.5	704.8	1017.3	1018.9	1061.3	1271.9	1290.0	1244.0
2005-2009	20.6	20.7	19.4	667.8	748.8	720.9	1054.2	1061.2	1087.2	1320.5	1333.5	1275.6
2010-2014	25.8	25.6	26.0	824.1	885.7	856.4	1274.1	1273.4	1314.4	1615.7	1605.6	1545.4
2015-2019	25.6	25.9	26.2	832.0	894.9	864.5	1285.7	1285.2	1325.5	1629.3	1619.9	1558.3

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**
1990-1994	1326.8	1326.0	1262.4	1618.5	1572.7	1492.4	1844.4	1746.2	1645.3
1995-1999	1317.2	1311.2	1258.9	1604.5	1564.4	1494.0	1839.8	1748.1	1653.6
2000-2004	1321.2	1323.2	1276.1	1617.9	1575.1	1506.4	1843.0	1749.6	1662.7
2005-2009	1371.4	1367.6	1308.9	1675.4	1635.9	1555.0	1920.1	1828.5	1729.6
2010-2014	1675.7	1647.8	1581.7	2039.2	1962.9	1880.7	2344.7	2212.3	2109.7
2015-2019	1689.8	1662.4	1595.0	2056.4	1980.5	1897.0	2364.9	2232.3	2128.1

Table 4.9: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Rupnagar

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	18.7	20.5	19.4	665.7	731.2	711.4	1046.5	1042.8	1073.0	1305.8	1318.8	1256.3
1995-1999	18.5	18.0	18.9	657.0	732.4	716.8	1040.3	1037.2	1071.4	1293.9	1305.7	1252.7
2000-2004	20.0	19.0	19.1	651.9	729.9	721.7	1040.5	1041.8	1085.4	1300.1	1318.8	1272.6
2005-2009	20.9	20.8	19.4	676.3	759.0	735.3	1073.3	1084.6	1117.7	1351.5	1367.8	1311.8
2010-2014	25.5	25.3	25.7	817.1	877.8	845.5	1262.2	1262.2	1300.5	1601.6	1592.5	1530.5
2015-2019	25.8	25.5	25.8	821.5	880.7	847.9	1267.6	1267.0	1306.1	1609.1	1600.3	1538.4

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	I	II	III	I	II	III	I	II	III
1990-1994	1356.8	1352.4	1288.0	1653.4	1605.5	1524.0	1885.9	1784.4	1682.4
1995-1999	1344.7	1338.8	1284.7	1638.7	1597.9	1526.2	1880.9	1787.2	1691.0
2000-2004	1350.4	1352.7	1305.8	1654.7	1611.9	1543.7	1888.3	1793.8	1707.0
2005-2009	1404.3	1403.1	1346.0	1717.9	1677.8	1598.6	1968.4	1875.3	1777.1
2010-2014	1661.3	1634.5	1566.6	2023.2	1948.3	1864.4	2327.4	2196.7	2091.2
2015-2019	1669.3	1642.7	1575.0	2035.1	1960.1	1876.2	2342.6	2210.8	2104.9

Table 4.10: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Amritsar

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	20.9	23.1	22.1	751.7	826.5	804.1	1183.0	1177.3	1211.8	1472.9	1491.2	1421.0
1995-1999	21.2	20.7	21.5	749.5	831.1	811.5	1180.1	1175.4	1214.3	1468.5	1480.3	1420.8
2000-2004	22.8	21.9	21.9	745.4	827.8	813.4	1180.4	1179.3	1225.4	1474.5	1492.1	1436.2
2005-2009	22.0	21.3	21.4	726.4	828.2	805.3	1166.3	1182.6	1221.5	1462.9	1459.5	1428.0
2010-2014	22.0	24.1	21.1	771.6	859.4	836.2	1222.7	1216.5	1247.7	1517.3	1530.4	1458.5
2015-2019	23.7	24.8	22.6	806.4	878.3	854.7	1262.8	1262.0	1310.9	1598.4	1599.8	1537.1

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	I	II	III	I	II	III	I	II	III
1990-1994	1531.3	1529.7	1456.8	1871.3	1817.9	1725.5	2135.4	2021.8	1905.1
1995-1999	1526.1	1518.1	1457.9	1862.0	1814.9	1732.4	2136.3	2028.9	1919.2
2000-2004	1531.8	1530.3	1473.6	1875.8	1824.0	1743.1	2138.9	2028.3	1925.4
2005-2009	1523.2	1532.2	1464.5	1860.0	1826.1	1736.4	2131.6	2041.1	1930.8
2010-2014	1575.8	1569.3	1495.1	1918.1	1862.2	1765.3	2185.6	2075.0	1962.7
2015-2019	1658.3	1641.4	1580.4	2025.0	1958.5	1871.4	2320.3	2196.9	2090.5

Table 4.11: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Kapurthala

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	20.6	22.4	21.2	728.3	800.1	777.7	1145.3	1139.4	1172.6	1426.5	1443.3	1375.6
1995-1999	20.5	20.1	20.6	724.4	802.6	783.4	1140.4	1134.7	1171.5	1418.1	1428.8	1370.9
2000-2004	22.1	21.2	21.1	720.5	800.6	786.9	1141.6	1140.5	1185.6	1426.5	1443.6	1390.6
2005-2009	22.3	22.6	20.7	730.9	818.5	793.8	1162.4	1175.1	1213.9	1465.3	1488.3	1420.9
2010-2014	24.1	25.4	23.1	821.8	889.0	858.8	1281.1	1277.7	1320.8	1623.0	1615.9	1544.4
2015-2019	24.5	25.7	22.9	830.5	897.4	866.2	1293.1	1288.6	1331.3	1637.0	1629.6	1557.3

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**
1990-1994	1482.8	1480.6	1410.3	1812.1	1760.6	1671.1	2068.7	1958.2	1845.1
1995-1999	1473.6	1465.3	1406.5	1797.7	1751.7	1672.2	2063.4	1959.2	1853.1
2000-2004	1481.7	1480.8	1426.9	1815.7	1766.0	1688.4	2071.2	1964.6	1865.7
2005-2009	1524.1	1524.9	1459.1	1862.0	1818.2	1727.3	2129.3	2029.4	1917.9
2010-2014	1683.1	1656.9	1588.6	2045.6	1970.9	1881.0	2346.1	2219.8	2106.4
2015-2019	1697.6	1671.1	1601.9	2064.3	1989.2	1898.3	2368.6	2240.9	2126.0

Table 4.12: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Jalandhar

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	20.6	22.4	21.2	728.9	800.7	778.4	1146.1	1140.3	1173.5	1427.6	1444.2	1376.5
1995-1999	20.5	20.1	20.8	724.6	803.0	783.8	1140.8	1135.1	1172.1	1418.6	1429.3	1371.5
2000-2004	22.1	21.2	21.1	721.0	801.4	787.8	1142.7	1141.6	1186.8	1427.8	1445.0	1391.9
2005-2009	21.4	21.1	20.7	706.8	796.5	773.8	1129.5	1141.7	1178.3	1417.2	1445.6	1381.3
2010-2014	20.3	21.5	19.1	707.8	790.6	795.2	1149.5	1151.0	1182.5	1425.5	1444.5	1382.1
2015-2019	25.9	26.4	21.9	836.2	900.7	868.4	1294.3	1291.1	1328.6	1637.4	1627.6	1559.5

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	I	II	III	I	II	III	I	II	III
1990-1994	1483.9	1481.6	1411.2	1813.3	1761.7	1672.1	2069.9	1959.3	1846.2
1995-1999	1474.1	1465.8	1407.1	1798.2	1752.2	1672.9	2064.0	1959.8	1853.7
2000-2004	1483.1	1482.2	1428.1	1817.2	1767.5	1689.8	2072.9	1966.2	1867.3
2005-2009	1475.3	1481.6	1416.8	1806.4	1768.4	1676.2	2063.1	1971.9	1864.9
2010-2014	1480.8	1481.0	1417.5	1807.5	1762.0	1673.6	2059.4	1961.0	1855.0
2015-2019	1699.4	1668.9	1599.8	2063.9	1987.2	1896.8	2369.2	2237.8	2125.6

Table 4.13: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Ludhiana

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	20.8	23.4	21.4	746.2	823.7	806.2	1180.1	1180.3	1217.3	1474.4	1494.8	1427.1
1995-1999	21.9	19.0	21.5	736.1	818.5	807.3	1171.2	1170.0	1209.7	1459.4	1475.6	1417.4
2000-2004	23.2	21.9	22.7	744.7	835.0	826.5	1190.9	1195.5	1249.0	1492.3	1516.6	1462.2
2005-2009	22.4	21.9	20.6	724.5	828.9	811.2	1172.1	1194.2	1237.6	1476.5	1508.4	1442.9
2010-2014	20.6	24.6	21.0	760.7	854.5	835.9	1215.0	1213.8	1248.9	1509.4	1529.5	1462.4
2015-2019	23.8	21.0	21.6	748.1	835.9	821.7	1196.8	1201.2	1245.4	1498.9	1520.0	1464.8

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	I	II	III	I	II	III	I	II	III
1990-1994	1532.8	1532.7	1463.0	1920.9	1824.4	1735.3	2140.5	2028.2	1914.3
1995-1999	1516.6	1511.5	1454.2	1914.6	1811.4	1733.5	2134.4	2030.1	1925.1
2000-2004	1551.5	1554.3	1500.0	1870.0	1853.2	1776.0	2170.9	2063.4	1963.0
2005-2009	1537.3	1546.3	1478.3	1898.5	1836.6	1747.9	2141.3	2051.0	1941.9
2010-2014	1567.9	1567.9	1498.9	1914.6	1861.9	1767.8	2178.1	2072.8	1962.4
2015-2019	1559.6	1559.5	1505.6	1871.4	2072.8	1785.5	2195.0	2085.4	1979.5

Table 4.14: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Moga

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	21.6	23.2	23.2	766.2	842.3	820.1	1204.3	1200.6	1235.4	1501.9	1516.6	1445.7
1995-1999	21.5	20.9	20.9	755.1	840.6	821.5	1194.3	1190.3	1228.9	1485.4	1499.3	1437.4
2000-2004	22.8	22.1	22.1	753.2	843.4	832.4	1201.4	1202.7	1251.0	1500.1	1521.1	1465.8
2005-2009	23.3	22.9	22.9	754.0	851.1	830.6	1206.4	1222.0	1268.3	1521.6	1549.4	1486.5
2010-2014	25.5	26.4	26.4	841.7	910.3	881.4	1308.1	1309.1	1354.6	1659.6	1656.2	1588.4
2015-2019	26.0	27.2	27.2	850.3	919.8	889.5	1320.3	1321.3	1366.0	1673.9	1670.7	1602.3

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	I	II	III	I	II	III	I	II	III
1990-1994	1560.5	1555.3	1482.0	1901.0	1847.1	1753.4	2168.7	2053.0	1935.6
1995-1999	1543.7	1537.2	1474.6	1883.2	1836.2	1752.8	2161.1	2053.2	1941.1
2000-2004	1558.2	1560.0	1504.2	1908.2	1859.4	1779.1	2178.2	2069.2	1966.3
2005-2009	1583.9	1588.5	1525.3	1937.8	1894.6	1806.4	2217.6	2114.9	2004.3
2010-2014	1725.1	1698.0	1629.0	2094.2	2018.9	1927.7	2400.4	2268.4	2153.5
2015-2019	1739.6	1713.2	1642.8	2113.0	2038.3	1946.8	2424.1	2291.4	2175.8

Table 4.15: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Fatehgarh Sahib

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	19.5	21.2	19.9	687.8	753.9	732.9	1079.5	1075.2	1105.5	1347.4	1358.7	1294.5
1995-1999	19.2	18.7	19.4	677.6	754.7	738.4	1072.8	1069.0	1103.8	1334.1	1346.1	1291.2
2000-2004	20.8	19.7	19.7	672.5	752.9	744.9	1074.3	1075.0	1119.8	1341.8	1360.7	1313.1
2005-2009	21.5	21.2	19.8	693.8	778.9	758.5	1105.3	1120.0	1159.2	1396.7	1416.2	1360.0
2010-2014	25.6	25.5	25.9	824.4	886.0	854.0	1274.4	1273.0	1310.3	1614.4	1603.6	1540.8
2015-2019	25.8	25.7	26.2	831.2	893.8	860.5	1283.3	1282.4	1320.2	1625.7	1616.7	1553.4

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	I	II	III	I	II	III	I	II	III
1990-1994	1399.7	1393.3	1327.4	1705.5	1655.5	1571.9	1946.8	1841.4	1736.9
1995-1999	1386.4	1380.3	1324.3	1690.4	1648.2	1574.5	1941.6	1844.8	1745.7
2000-2004	1393.6	1395.6	1347.7	1708.5	1664.7	1595.1	1951.8	1854.5	1765.6
2005-2009	1451.9	1452.6	1395.3	1776.7	1735.5	1655.9	2035.1	1939.4	1840.0
2010-2014	1674.3	1645.7	1577.1	2037.1	1961.6	1877.8	2344.0	2212.3	2106.4
2015-2019	1686.2	1659.3	1590.4	2054.0	1980.0	1895.4	2365.3	2233.5	2126.4

Table 4.16: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Patiala

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	19.7	21.4	20.1	695.8	762.2	741.0	1091.4	1086.9	1117.5	1362.3	1373.3	1308.4
1995-1999	19.5	18.9	19.6	685.9	763.4	746.7	1085.3	1081.2	1116.3	1349.5	1361.4	1305.8
2000-2004	21.0	19.9	19.9	680.5	761.7	753.6	1086.9	1087.3	1132.2	1357.1	1375.9	1327.6
2005-2009	21.6	20.9	20.0	695.4	792.5	775.2	1120.7	1137.1	1177.5	1408.5	1437.8	1378.9
2010-2014	22.7	23.1	21.3	776.1	868.8	852.4	1237.9	1234.5	1267.3	1532.8	1552.7	1487.4
2015-2019	26.9	24.5	25.0	817.0	883.4	852.5	1267.5	1266.0	1302.8	1598.6	1594.9	1533.7

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**
1990-1994	1415.1	1408.2	1341.6	1723.8	1673.3	1588.9	1968.1	1861.7	1756.1
1995-1999	1402.4	1396.0	1339.2	1709.9	1666.9	1592.5	1964.2	1866.2	1765.9
2000-2004	1409.5	1411.3	1362.6	1727.6	1683.4	1613.1	1974.1	1875.7	1785.8
2005-2009	1465.9	1474.6	1414.8	1791.6	1753.5	1670.3	2047.7	1959.1	1860.5
2010-2014	1591.0	1593.0	1524.1	1945.7	1892.4	1797.8	2215.8	2108.1	1997.1
2015-2019	1657.6	1637.3	1571.7	2026.5	1959.3	1874.2	2331.7	2202.6	2095.3

Table 4.17: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Sangrur

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	21.5	22.9	22.1	759.3	833.7	811.8	1192.5	1188.3	1222.9	1487.5	1501.0	1430.8
1995-1999	21.4	20.7	21.7	749.1	833.4	814.7	1184.2	1179.8	1218.1	1472.5	1485.8	1424.6
2000-2004	23.0	21.8	22.0	746.7	835.5	824.7	1190.7	1191.0	1238.5	1485.9	1505.9	1451.1
2005-2009	23.2	22.6	21.1	748.8	844.6	824.5	1197.5	1213.0	1258.9	1510.6	1536.9	1475.5
2010-2014	25.9	25.9	26.5	841.3	908.7	879.5	1305.5	1307.5	1352.3	1656.4	1651.4	1587.5
2015-2019	26.1	26.1	26.6	847.4	914.8	884.8	1313.9	1315.1	1359.6	1666.1	1660.9	1596.5

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**
1990-1994	1545.4	1539.2	1466.7	1881.9	1828.0	1735.8	2147.6	2032.5	1917.1
1995-1999	1530.3	1523.5	1461.3	1866.3	1819.4	1737.3	2142.4	2035.4	1924.7
2000-2004	1543.4	1544.4	1489.0	1889.6	1840.7	1761.5	2157.5	2049.2	1947.7
2005-2009	1571.9	1576.0	1513.4	1923.1	1879.8	1793.4	2201.3	2098.5	1990.4
2010-2014	1720.0	1694.3	1624.6	2090.9	2016.6	1930.7	2402.7	2269.5	2160.4
2015-2019	1730.1	1704.2	1634.1	2104.0	2029.7	1943.3	2419.0	2285.0	2175.2

Table 4. 18: Pentads variability of AGDD (°C day) at different phenological stages of rice under three transplanting windows in Firozpur

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	21.7	23.6	22.7	773.9	850.2	827.1	1215.8	1211.4	1246.0	1515.6	1530.8	1530.8
1995-1999	21.6	21.2	22.2	764.7	850.6	831.4	1208.4	1204.6	1243.9	1503.3	1517.7	1517.7
2000-2004	23.5	22.2	22.5	761.2	851.3	840.2	1213.9	1215.3	1263.7	1516.1	1536.9	1536.9
2005-2009	23.5	23.1	20.7	763.1	861.4	840.1	1220.9	1235.6	1281.1	1538.5	1566.0	1566.0
2010-2014	25.8	26.5	22.0	846.9	919.4	893.0	1321.5	1324.8	1371.6	1677.2	1674.3	1674.3
2015-2019	26.0	26.7	22.2	853.1	925.9	899.4	1330.8	1333.5	1380.9	1688.3	1685.6	1685.6

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**
1990-1994	1574.9	1569.9	1494.8	1918.6	1863.6	1768.6	2188.9	2071.7	1952.5
1995-1999	1562.3	1556.2	1493.6	1906.9	1859.6	1775.2	2188.3	2079.4	1966.5
2000-2004	1575.0	1576.0	1519.1	1928.6	1879.1	1797.9	2202.0	2091.2	1986.9
2005-2009	1601.4	1606.0	1541.8	1959.8	1917.2	1829.6	2247.8	2144.5	2032.3
2010-2014	1743.3	1716.0	1645.7	2111.8	2034.9	1942.0	2415.8	2283.0	2168.4
2015-2019	1754.9	1727.8	1657.7	2127.3	2050.3	1957.6	2434.7	2301.1	2186.2

Table 4.19: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Faridkot

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	21.8	23.7	22.8	776.4	853.0	829.8	1219.7	1215.7	1250.2	1520.7	1535.7	1462.9
1995-1999	21.6	21.2	22.3	765.9	852.6	833.6	1211.3	1207.9	1247.4	1507.0	1522.1	1459.9
2000-2004	23.5	22.2	22.5	762.9	854.4	844.1	1218.4	1220.4	1269.4	1521.9	1543.4	1486.8
2005-2009	23.6	23.1	20.7	763.7	861.9	840.8	1222.2	1236.7	1283.2	1540.5	1568.6	1506.5
2010-2014	25.9	26.6	21.9	848.7	919.7	892.1	1321.9	1324.1	1370.7	1677.3	1674.3	1605.6
2015-2019	26.0	26.7	22.1	854.4	926.2	898.3	1330.8	1332.6	1379.4	1687.8	1685.2	1616.3

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	I	II	III	I	II	III	I	II	III
1990-1994	1580.2	1574.9	1499.4	1924.3	1869.3	1773.8	2195.2	2077.7	1957.9
1995-1999	1566.3	1560.6	1497.8	1912.0	1864.8	1780.2	2194.0	2085.1	1971.9
2000-2004	1581.1	1582.6	1525.9	1936.0	1887.1	1806.0	2210.9	2100.2	1995.9
2005-2009	1603.7	1608.9	1545.1	1964.0	1921.8	1835.2	2254.4	2150.9	2038.7
2010-2014	1743.5	1716.3	1646.4	2114.5	2038.4	1946.1	2421.8	2288.7	2172.6
2015-2019	1754.5	1727.6	1657.6	2129.0	2053.3	1960.8	2439.8	2306.3	2189.6

Table 4.20: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Muktsar

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	21.9	23.7	22.8	778.3	854.7	831.6	1222.2	1218.0	1252.7	1523.8	1538.5	1465.5
1995-1999	21.7	21.3	22.4	768.4	855.0	836.0	1214.6	1210.9	1250.4	1510.9	1525.7	1463.3
2000-2004	23.6	22.2	22.6	764.7	856.2	845.7	1220.9	1222.7	1271.5	1524.8	1546.1	1489.2
2005-2009	23.7	23.2	20.8	767.2	866.3	845.3	1228.0	1242.5	1289.1	1547.3	1575.6	1513.4
2010-2014	26.0	26.8	22.2	858.6	932.1	904.5	1338.1	1341.0	1388.3	1697.0	1695.5	1626.4
2015-2019	26.2	27.0	22.4	865.0	938.5	910.2	1347.1	1349.3	1396.5	1707.7	1706.2	1636.7

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	I	II	III	I	II	III	I	II	III
1990-1994	1583.3	1577.7	1502.0	1927.7	1872.4	1776.9	2199.2	2081.5	1961.7
1995-1999	1570.2	1564.3	1501.3	1916.5	1869.1	1784.5	2199.4	2090.2	1976.9
2000-2004	1584.2	1585.3	1528.3	1939.5	1890.4	1809.2	2215.2	2104.2	1999.7
2005-2009	1610.7	1616.0	1552.2	1972.5	1930.3	1843.5	2264.1	2160.3	2048.1
2010-2014	1764.1	1738.1	1667.9	2140.6	2065.3	1972.3	2452.2	2318.3	2201.1
2015-2019	1775.1	1749.2	1678.6	2155.2	2080.0	1986.5	2470.2	2335.5	2216.9

Table 4.21: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Bathinda

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	21.8	23.4	22.5	771.8	847.5	825.0	1212.1	1207.9	1242.7	1511.5	1525.7	1513.1
1995-1999	21.6	21.1	22.1	761.7	847.4	828.4	1204.0	1199.8	1238.8	1497.3	1511.3	1503.5
2000-2004	23.4	22.2	22.4	758.9	849.3	838.5	1210.6	1211.5	1259.7	1511.1	1531.7	1514.9
2005-2009	23.2	21.6	21.6	746.0	856.1	838.4	1209.2	1227.0	1270.7	1517.6	1551.8	1536.9
2010-2014	21.9	25.3	22.9	802.7	893.5	871.2	1271.7	1265.7	1298.8	1575.8	1589.2	1680.9
2015-2019	22.9	21.4	21.2	750.7	839.5	825.2	1199.1	1206.3	1254.8	1506.5	1529.8	1764.8

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**
1990-1994	1570.5	1564.5	1490.2	1912.2	1857.5	1763.3	2181.8	2065.1	1947.1
1995-1999	1556.1	1549.6	1486.7	1898.4	1851.0	1767.3	2178.9	2070.3	1957.7
2000-2004	1569.7	1570.7	1514.2	1921.6	1872.3	1791.7	2194.2	2084.1	1980.5
2005-2009	1579.4	1590.4	1522.4	1927.4	1888.9	1799.4	2204.6	2109.9	2000.3
2010-2014	1637.7	1628.4	1549.9	1988.3	1930.9	1829.3	2262.5	2149.0	2029.4
2015-2019	1567.3	1569.1	1514.4	1927.7	1887.4	1802.3	2210.3	2104.3	1999.5

Table 4.22: Pentads variability of AGDD (ºC day) at different phenological stages of rice under three transplanting windows in Mansa

Pentad	Transplanting			Maximum Tillering			Booting			50% Panicle initiation		
	I	II	III	I	II	III	I	II	III	I	II	III
1990-1994	22.1	23.3	22.5	774.2	847.1	824.8	1212.4	1207.7	1242.5	1513.1	1524.7	1452.4
1995-1999	21.9	21.3	22.3	766.8	851.2	832.4	1209.5	1204.0	1243.5	1503.5	1516.5	1454.1
2000-2004	23.6	22.5	22.5	762.5	853.0	841.9	1215.8	1214.8	1261.6	1514.9	1534.3	1476.8
2005-2009	23.6	22.8	21.4	762.5	860.5	841.4	1220.1	1234.1	1282.0	1536.9	1563.7	1502.4
2010-2014	26.1	26.1	26.8	853.1	924.3	895.8	1326.2	1328.8	1374.2	1680.9	1676.5	1611.5
2015-2019	27.6	28.3	28.3	898.6	970.3	937.6	1393.0	1393.2	1439.6	1764.8	1759.3	1690.8

	Anthesis			Grain Filling			Physiological Maturity		
Pentad	I	II	III	I	II	III	I	II	III
1990-1994	1571.7	1563.2	1488.4	1910.8	1855.2	1762.2	2182.3	2065.7	1948.9
1995-1999	1562.4	1554.8	1491.3	1904.4	1856.5	1773.9	2188.0	2079.2	1967.2
2000-2004	1573.3	1573.4	1515.5	1924.4	1874.7	1793.9	2198.7	2088.5	1984.5
2005-2009	1599.4	1603.6	1540.8	1956.6	1912.1	1826.3	2240.4	2135.2	2026.5
2010-2014	1745.3	1719.9	1649.1	2120.0	2045.6	1958.4	2434.7	2300.3	2189.2
2015-2019	1832.4	1805.6	1731.3	2230.0	2152.1	2061.1	2565.7	2423.6	2306.9

4.2.5 Trend analysis of heat use efficiency (HUE) of rice under transplanting window I

The data from 1990-2018 was analyzed for trends (increasing or decreasing) in heat use efficiency (HUE) under transplanting window I and presented in Figures from 4.57 to 4.73. Variation in heat use efficiency was observed during different time period. It was observed that there was increasing trend of heat use efficiency (HUE) in Hoshiarpur, Kapurthala, Jalandhar, Ludhiana, Moga, Patiala, Sangrur, Firozpur, Bathinda. In Gurdaspur, Fategarh Sahib, Faridkot, Muktsar and Mansa no major trend was observed in the value of HUE in different year indicating less variation. The R^2 value was highest at Ludhiana and Bathinda (0.64) and lowest at Gurdaspur (0.001).

Among all the districts the highest rate of increase in HUE was observed in Ludhiana (0.019 kg/ha/°C day year^{-1}) followed by Bathinda (0.016 kg/ha/°C day year^{-1}) and decreasing rate was found in Rupnagar (-0.002 kg/ha/ °C day year^{-1}). It was 0.006 kg/ha/°C day year^{-1} in Hoshiarpur, 0.012 kg/ha/ °C day year^{-1} in Kapurthala, 0.006 kg/ha/°C day year^{-1} in Jalandhar, 0.011 kg/ha/°C day year^{-1} in Moga, 0.002 kg/ha/°C day year^{-1} in Fatehgarh Sahib, 0.006 kg/ha/°C day year^{-1} in Patiala, 0.014 kg/ha/ °C day year^{-1} in Sangrur, 0.003kg/ha/°C day year^{-1} in Faridkot, 0.006 kg/ha/°C day year^{-1} in Firozpur, 0.001 kg/ha/°C day year^{-1}in Muktsar, , 0.003 kg/ha/°C day year^{-1} in Mansa. The rate of decrease was -0.003 kg/ha/°C day year^{-1} and -0.002 kg/ha/°C day year^{-1} for S.B.S. Nagar and Amritsar, respectively.

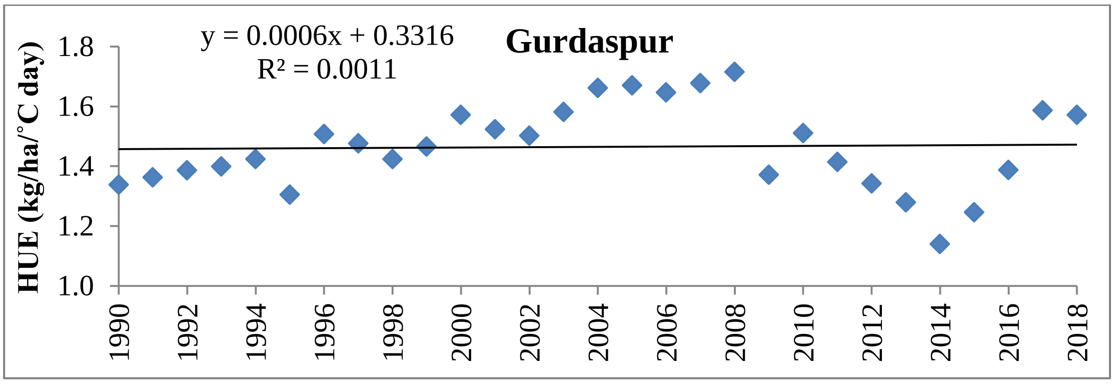


Fig.4.57: Variability in heat use efficiency (HUE) of rice from 1990-2018 at Gurdaspur under transplanting window I

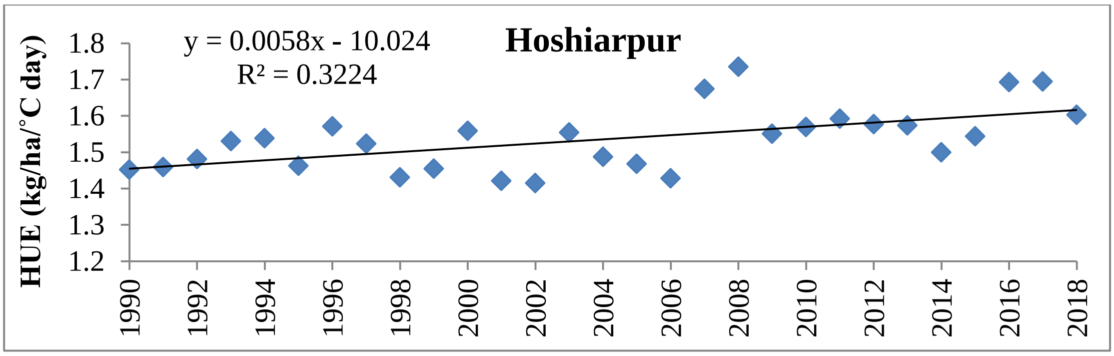


Fig.4.58: Variability in heat use efficiency (HUE) of rice from 1990-2018 at Hoshiarpur under transplanting window I

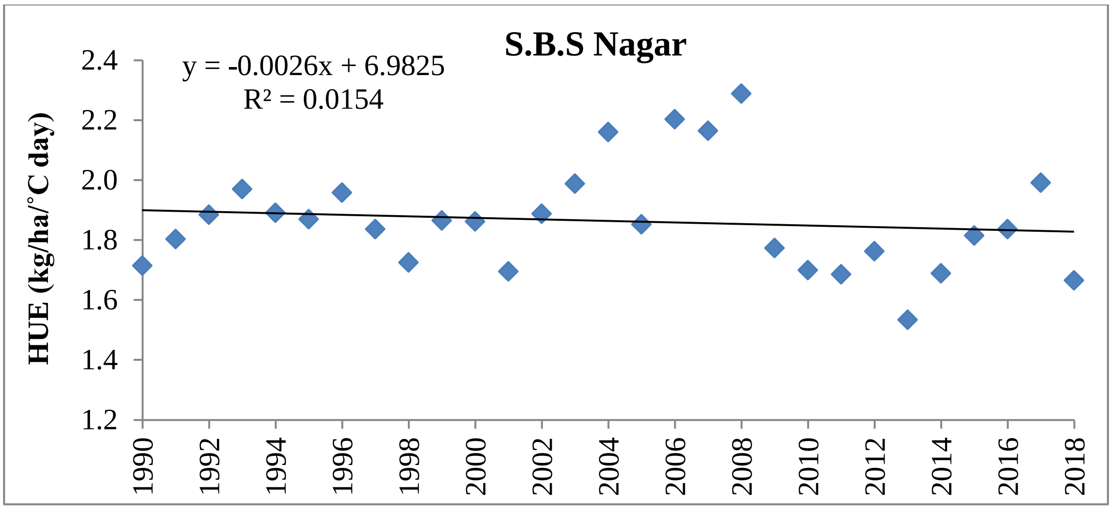


Fig 4.59 : **Variability in heat use efficiency (HUE) of rice from 1990-2018 at S.B.S Nagar under transplanting window I**

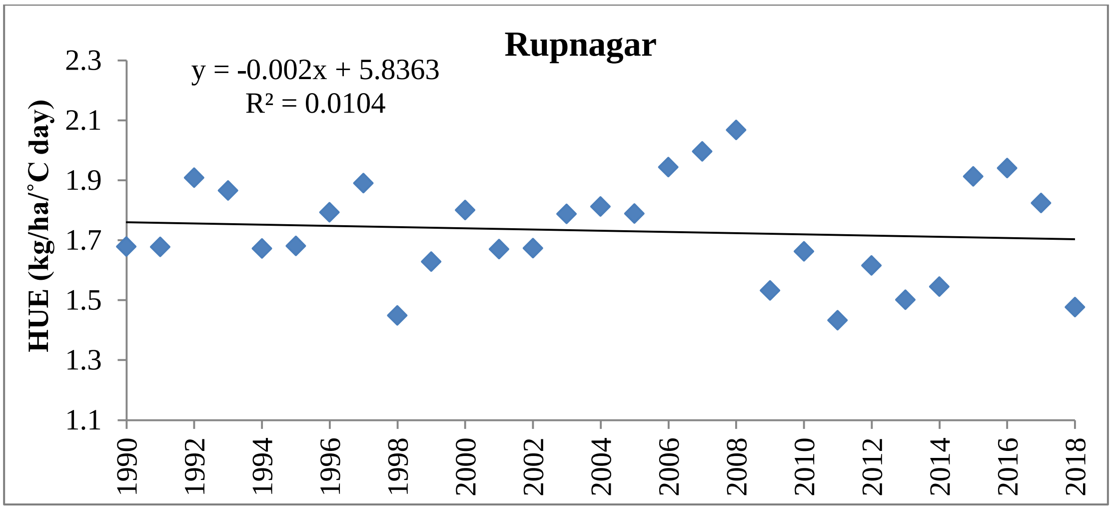


Fig 4.60: **Variability in heat use efficiency (HUE) of rice from 1990-2018 at Rupnagar under transplanting window I**

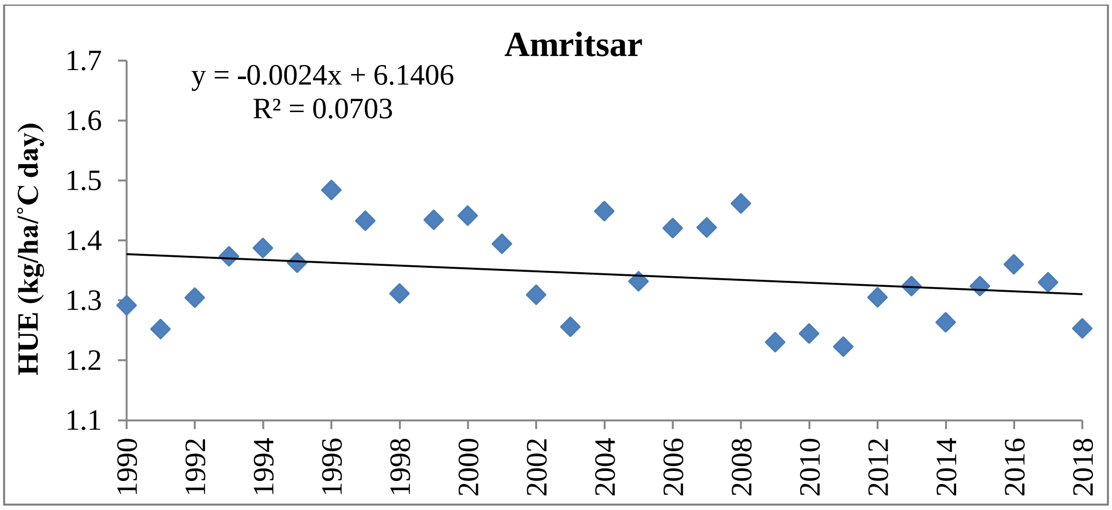


Fig 4.61: **Variability in heat use efficiency (HUE) of rice from 1990-2018 at Amritsar under transplanting window I**

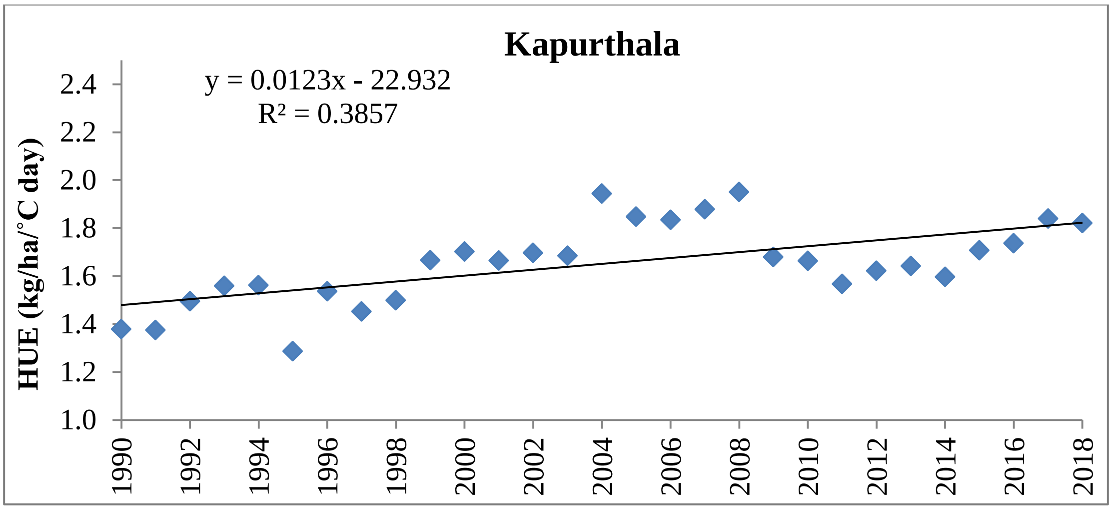


Fig 4.62: Variability in heat use efficiency (HUE) of rice from 1990-2018 at Kapurthala under transplanting window I

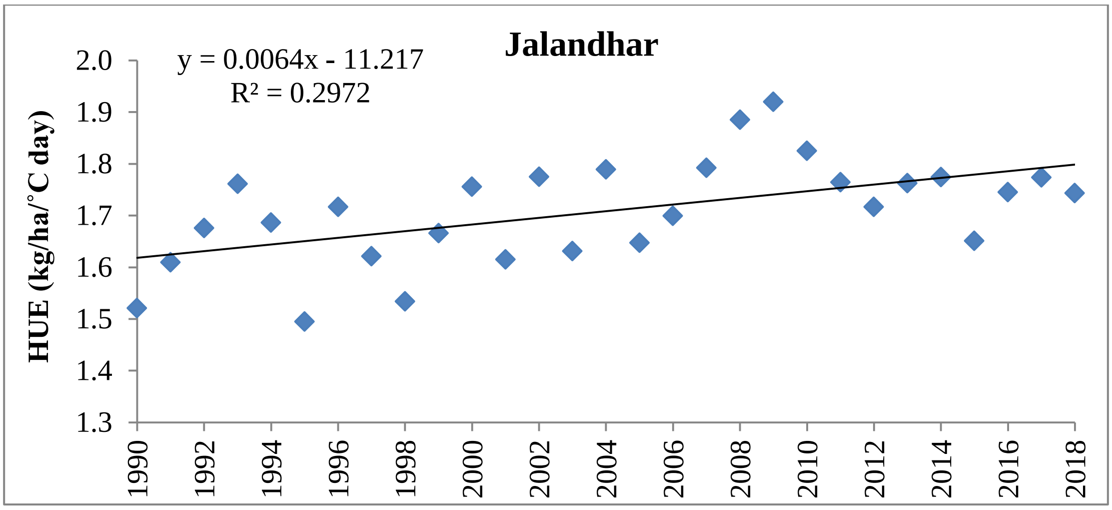


Fig 4.63: Variability in heat use efficiency (HUE) of rice from 1990-2018 at Jalandhar under transplanting window I

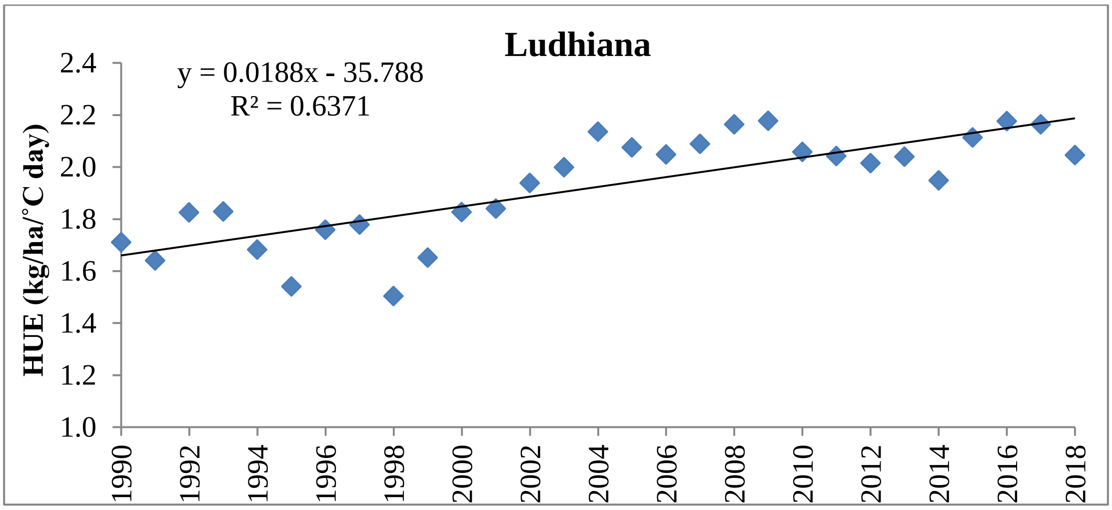


Fig 4.64: Variability in heat use efficiency (HUE) of rice from 1990-2018 at Ludhiana under transplanting window I

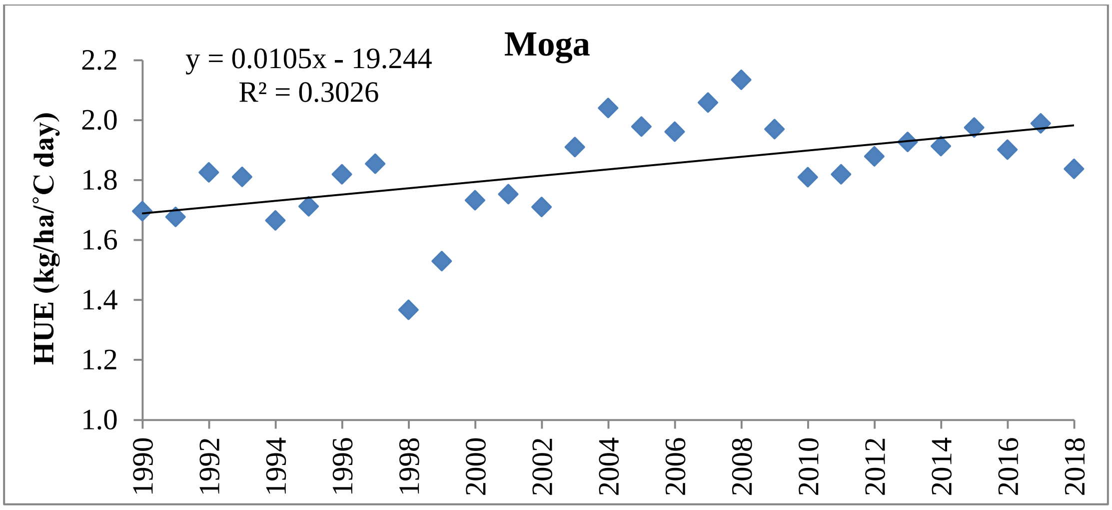


Fig 4.65: Variability in heat use efficiency (HUE) of rice from 1990-2018 at Moga under transplanting window I

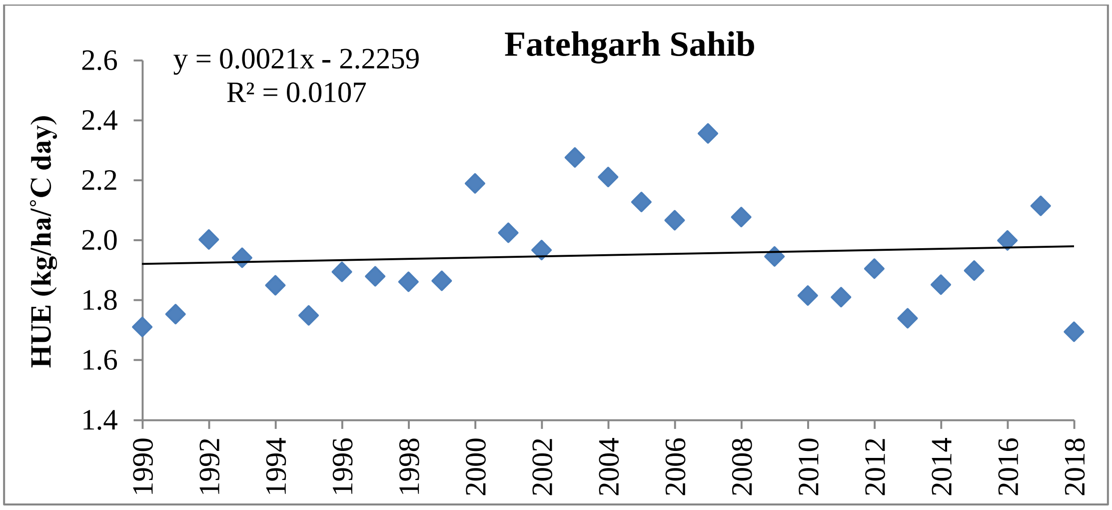


Fig 4.66: Variability in heat use efficiency (HUE) of rice from 1990-2018 at Fatehgarh Sahib under transplanting window I

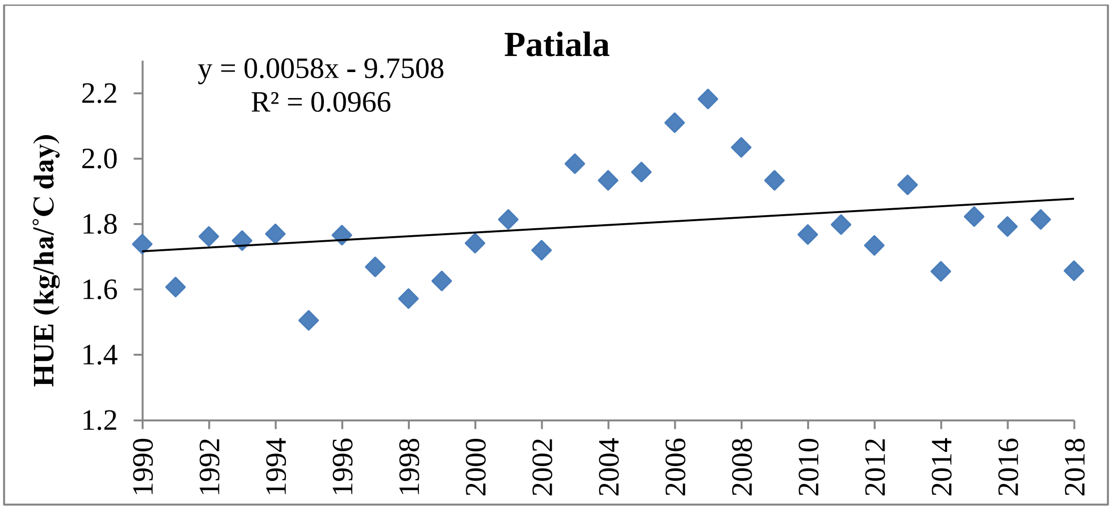


Fig 4.67 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Patiala under transplanting window I

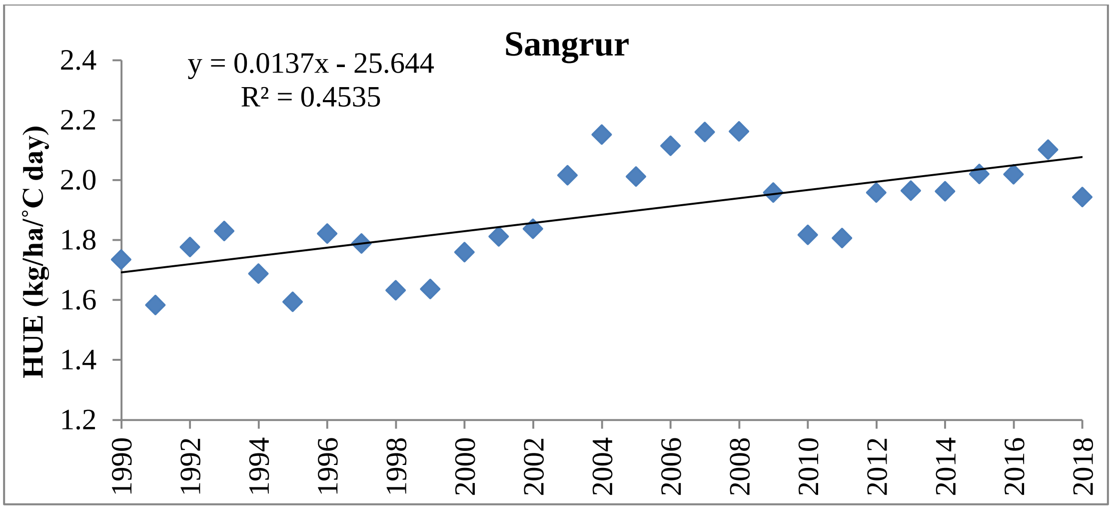


Fig 4.68 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Sangrur under transplanting window I

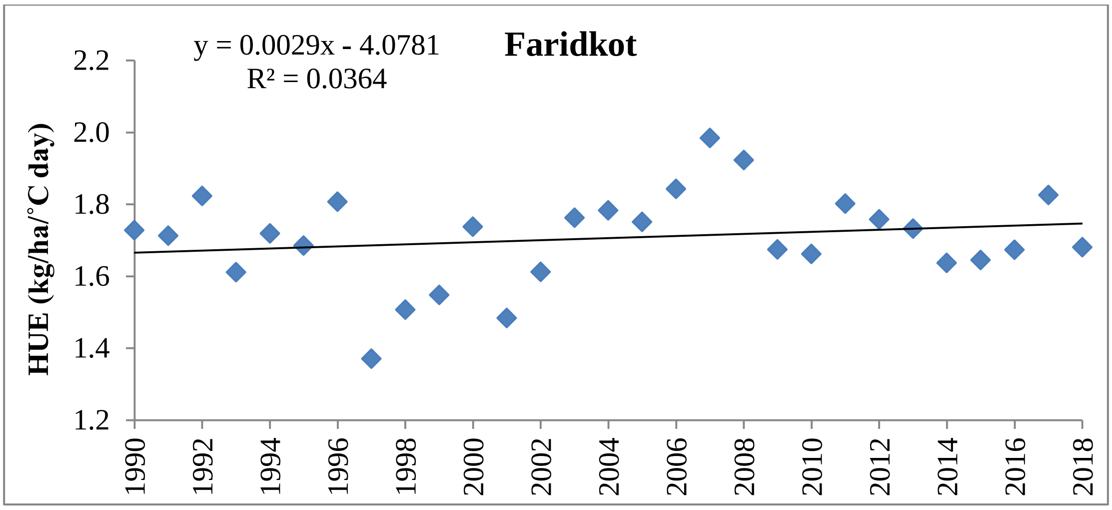


Fig 4.69 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Faridkot under transplanting window I

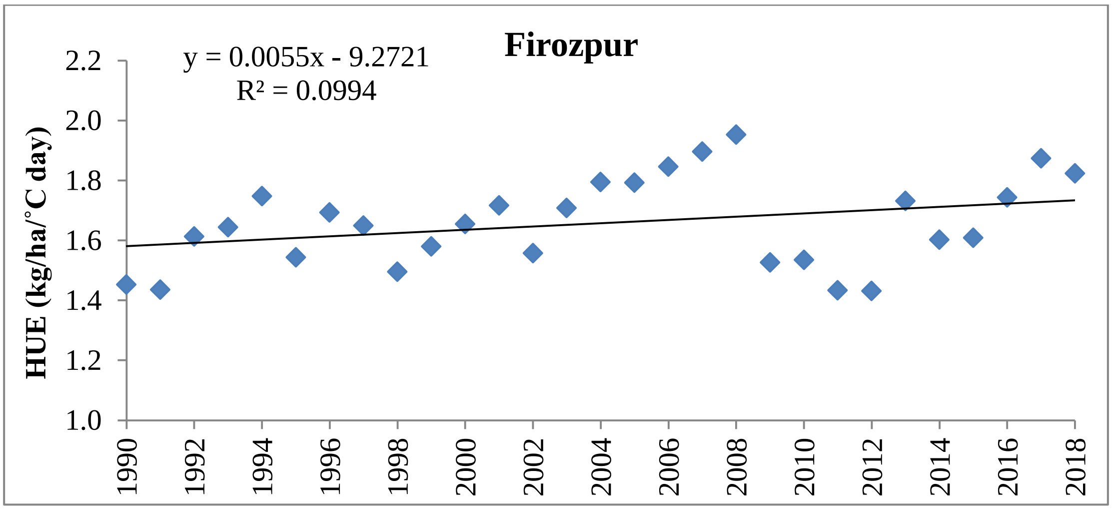


Fig 4.70 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Firozpur under transplanting window I

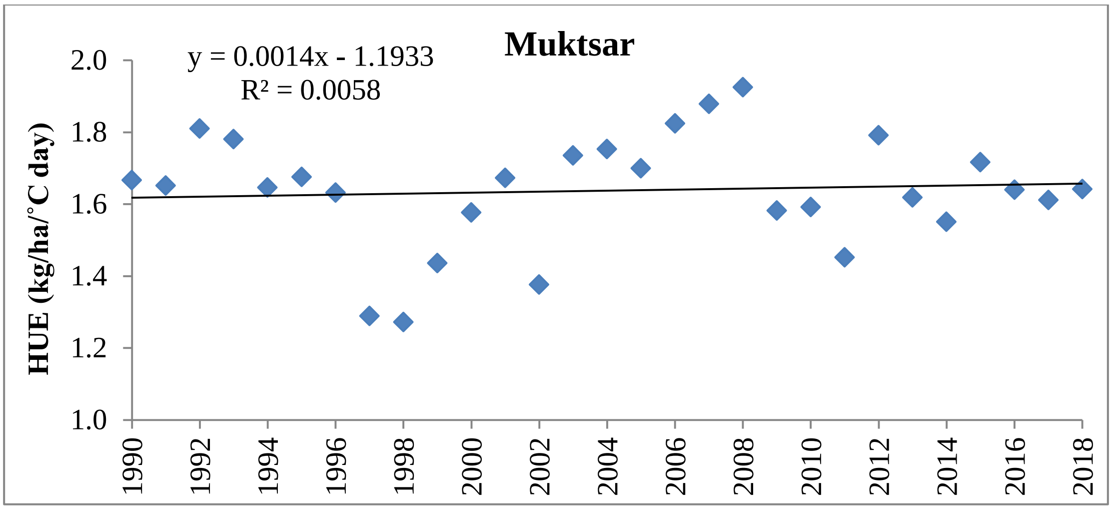


Fig 4.71 : **Variability in heat use efficiency (HUE) of rice from 1990-2018 at Muktsar under transplanting window I**

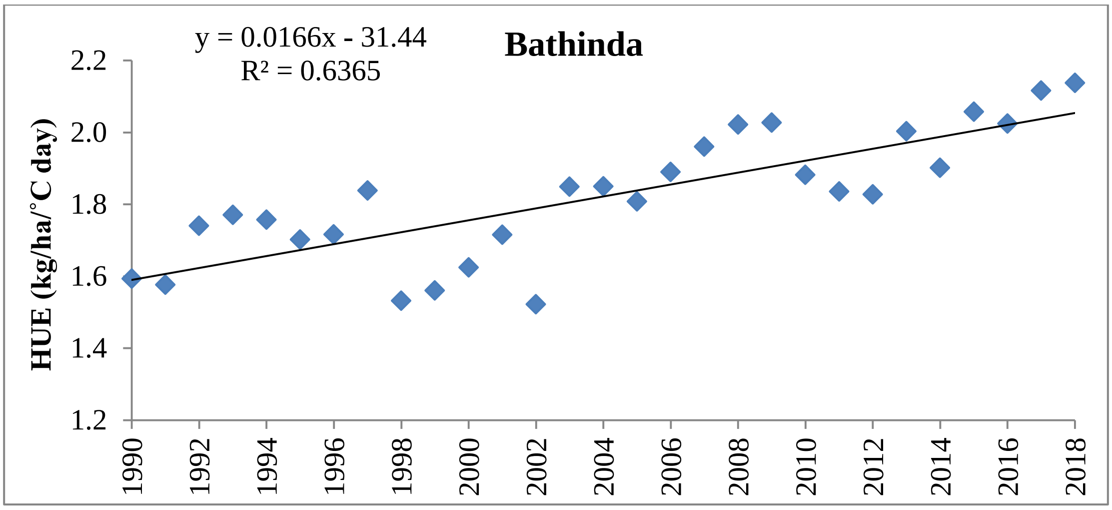


Fig 4.72 : **Variability in heat use efficiency (HUE) of rice from 1990-2018 at Bathinda under transplanting window I**

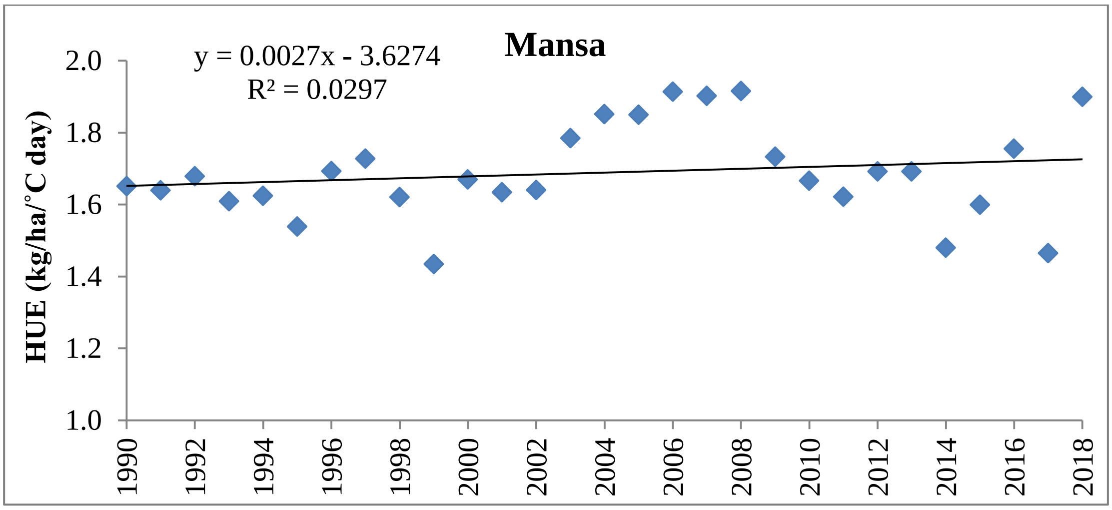


Fig 4.73 : **Variability in heat use efficiency (HUE) of rice from 1990-2018 at Mansa under transplanting window I**

4.2.6 Trend analysis of heat use efficiency (HUE) of rice under transplanting window II

The data analysis from 1990-2018 was carried out to observe increasing and decreasing trends in heat use efficiency (HUE**)** during different time period. The results are presented in Figures 4.74 to 4.90. It was observed that there was increasing trend of heat use efficiency (HUE**)** in Hoshiarpur, Kapurthala, Jalandhar, Ludhiana, Moga, Patiala, Sangrur, Firozpur, Bathinda. In Gurdaspur, SBS Nagar, Fategarh Sahib, Faridkot, Muktsar and Mansa no major trend was observed in the value of HUE in different year indicating less variation in HUE. The R^2 value was highest at Ludhiana and Bathinda (0.64) and lowest at Gurdaspur (0.003). The decreasing trend was observed in Rupnagar and Amritsar.

Among all the districts the highest rate of HUE increased was observed for Ludhiana (0.0195 kg/ha/°C day year^{-1}) followed by Bathinda (0.017 kg/ha/°C day year^{-1}) and highest decreasing rate was in Rupnagar (-0.001 kg/ha/°C day year^{-1}) followed by Amritsar (-0.002 kg/ha/°C day year^{-1}). For Hoshiarpur, Kapurthala, Jalandhar, Moga, Patiala, Sangrur, Faridkot, Firozpur value of the rate of increase was 0.0064 kg/ha/°C day year^{-1}, 0.0133kg/ha/°C day year^{-1}, 0.0066 kg/ha/°C day year^{-1}, 0.0112 kg/ha/°C day year^{-1}, 0.0058kg/ha/°C day year^{-1}, 0.0147kg/ha/°C day year^{-1}, 0.0059kg/ha/°C day year^{-1} .

In Gurdaspur, SBSN, Fatehgarh Sahib, Faridkot, Muktsar and Mansa the rate was 0.0011kg/ha/°C day year^{-1}, 0.0024kg/ha/°C day year^{-1}, 0.0024kg/ha/°C day year^{-1}, 0.003 kg/ha/ °C day year^{-1}, 0.0016 kg/ha/°C day year^{-1} and 0.0034 kg/ha/°C day year^{-1}.

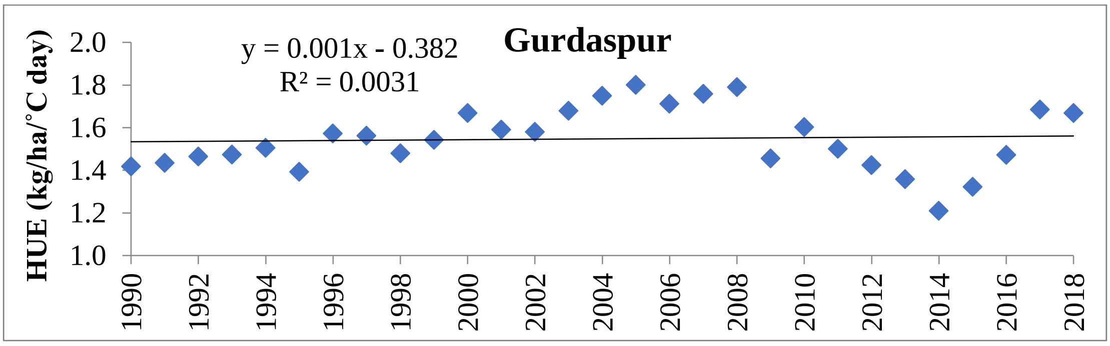


Fig 4.74 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Gurdaspur under transplanting window II

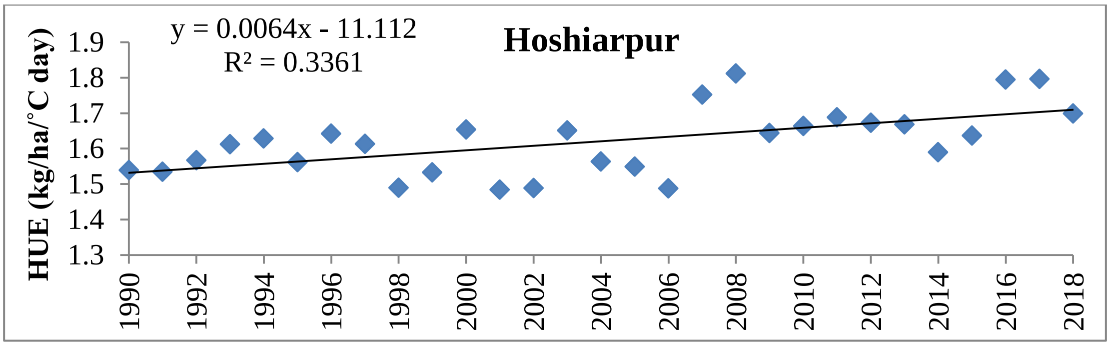


Fig 4.75 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Hoshiarpur under transplanting window II

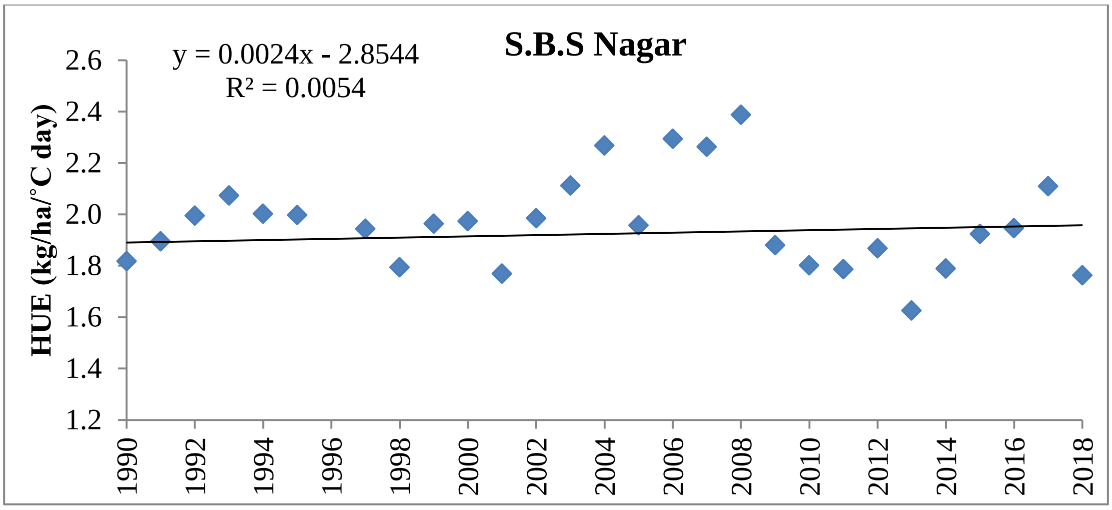


Fig 4.76 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at S.B.S Nagar under transplanting window II

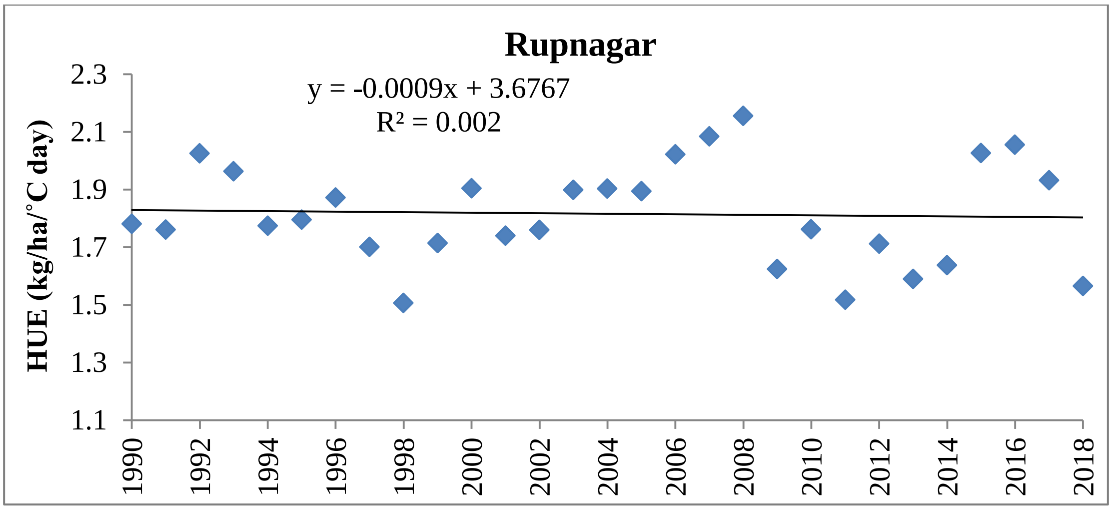


Fig 4.77 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Rupnagar under transplanting window II

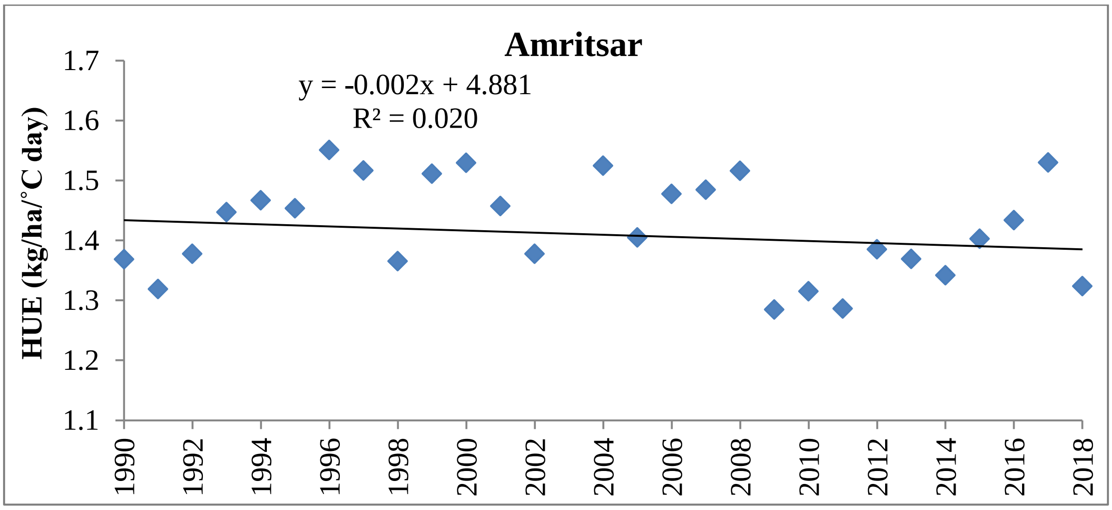


Fig 4.78 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Amritsar under transplanting window II

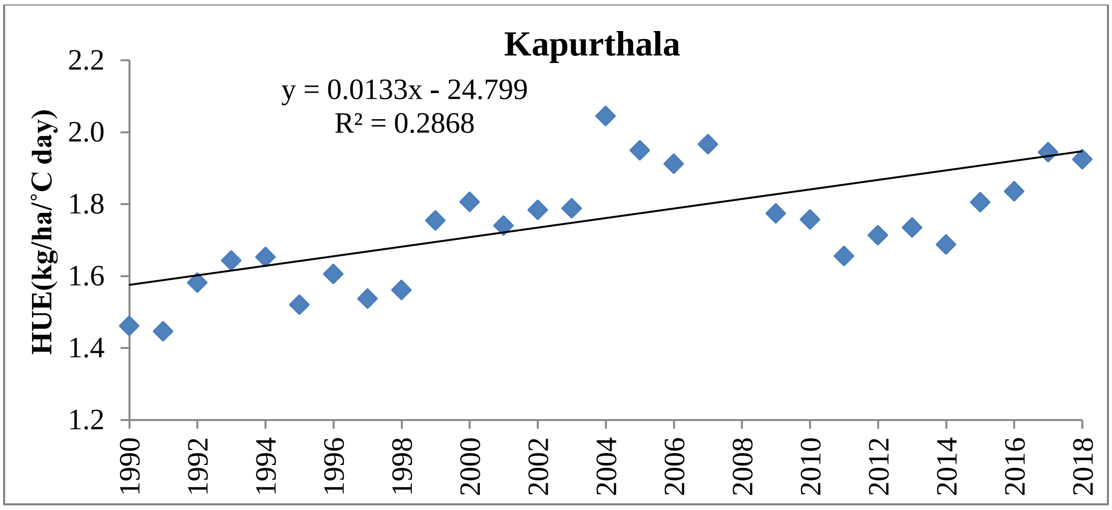


Fig 4.79 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Kapurthala under transplanting window II

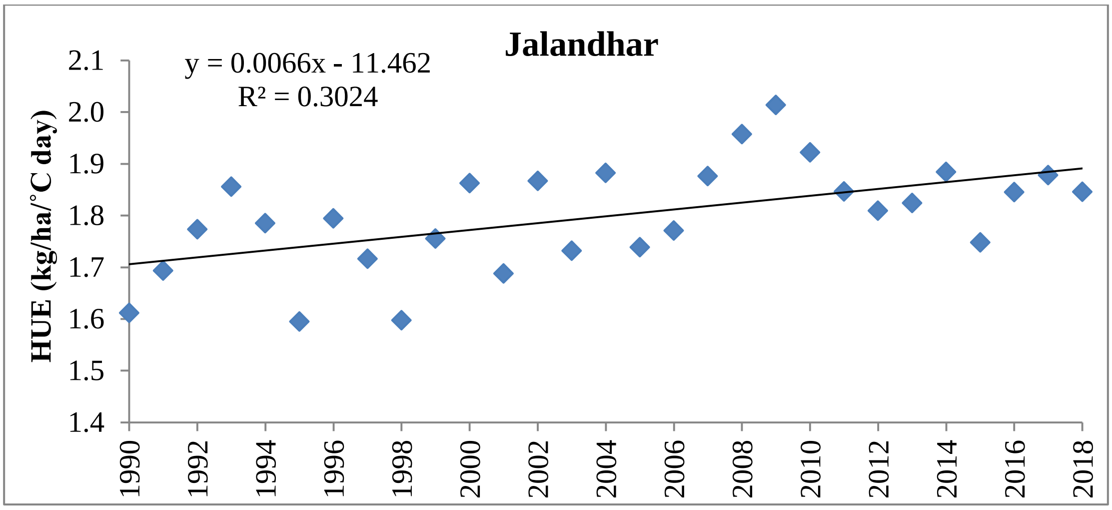


Fig 4.80 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Jalandhar under transplanting window II

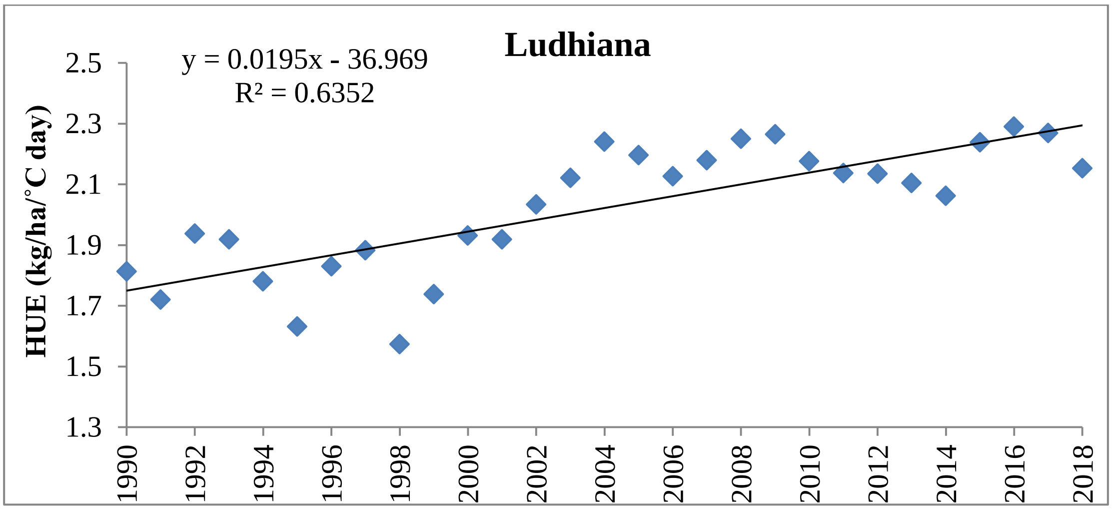


Fig 4.81 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Ludhiana under transplanting window II

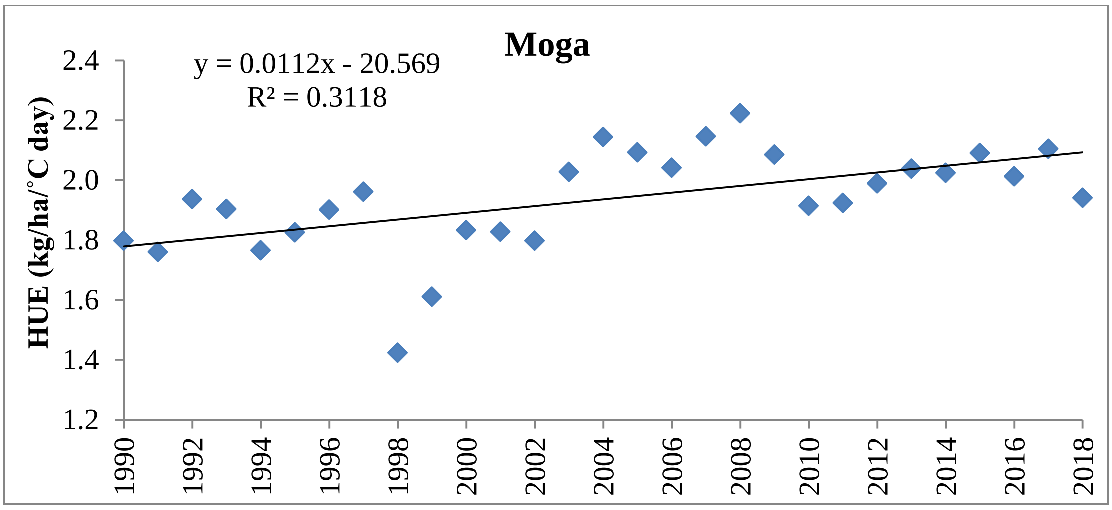


Fig 4.82 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Moga under transplanting window II

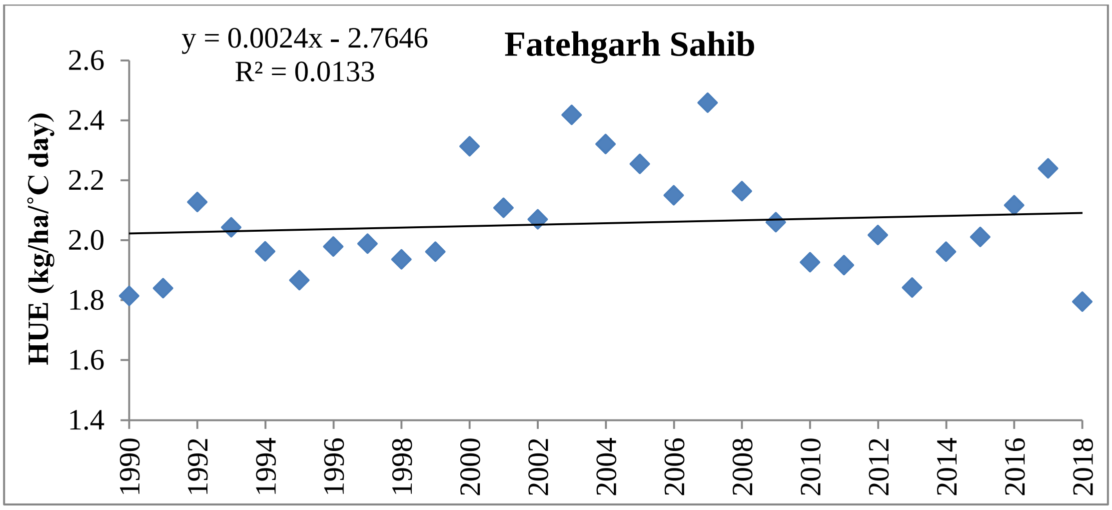


Fig 4.83 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Fatehgarh Sahib under transplanting window II

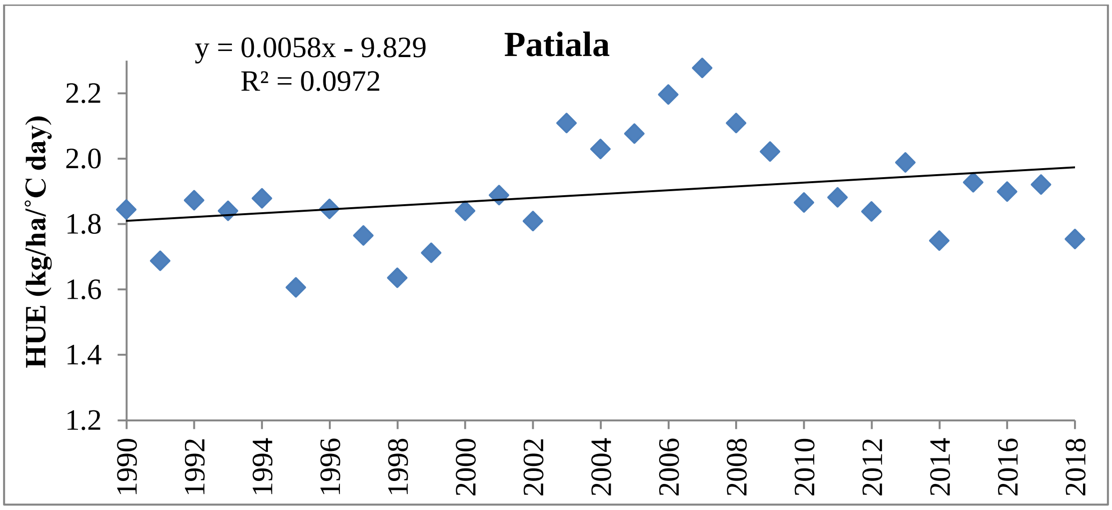


Fig 4.84 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Patiala under transplanting window II

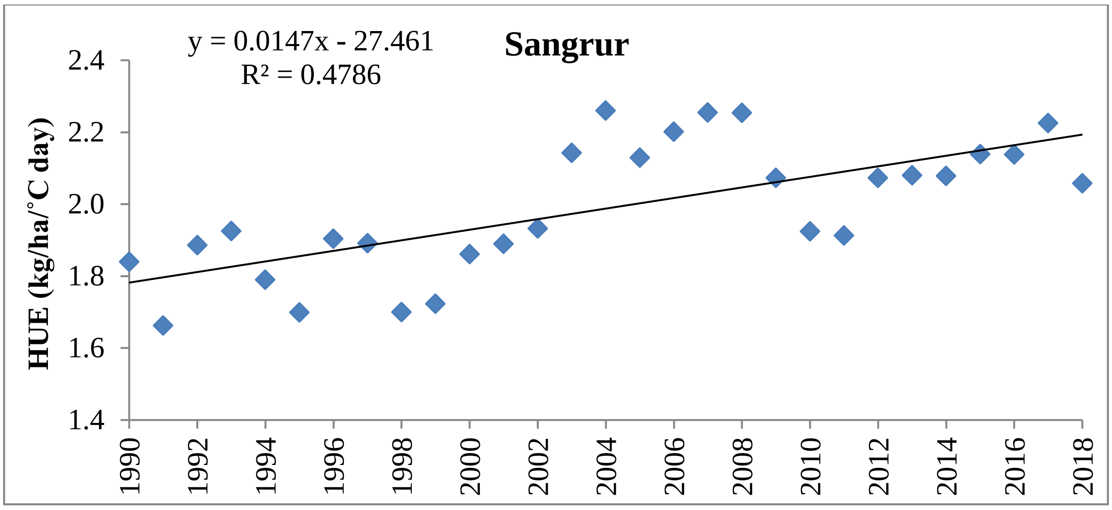


Fig 4.85 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Sangrur under transplanting window II

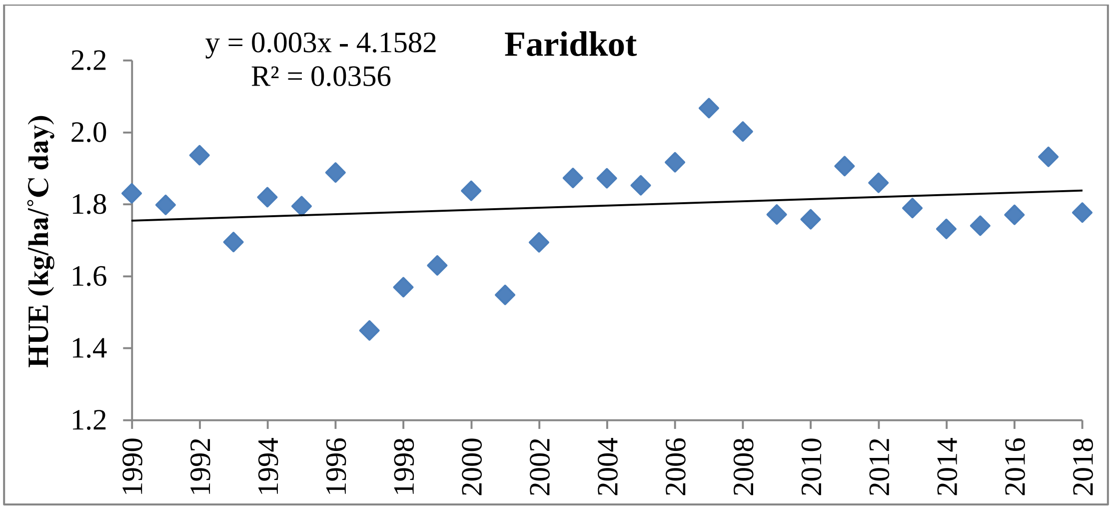


Fig 4.86 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Faridkot under transplanting window II

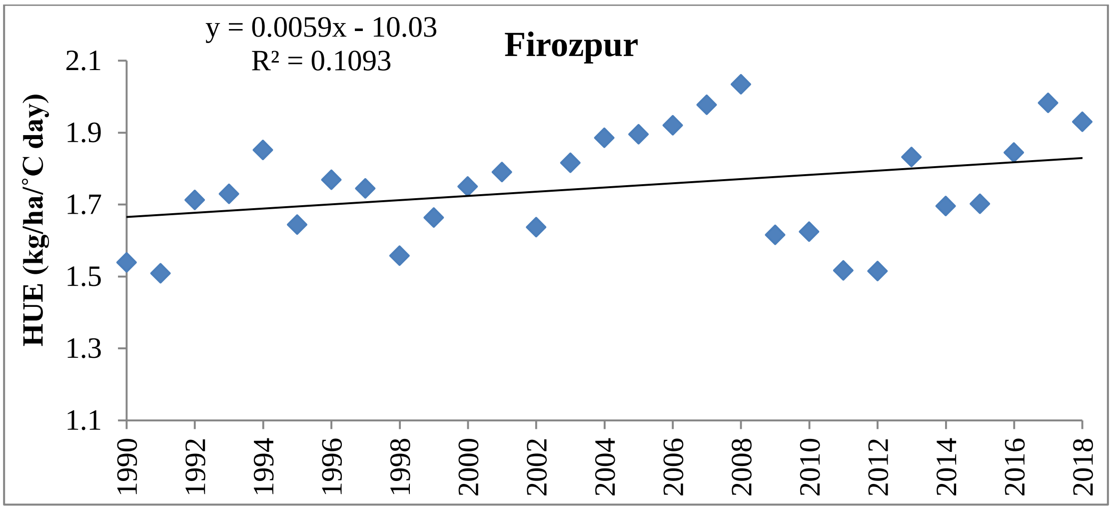


Fig 4.87 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Firozpur under transplanting window II

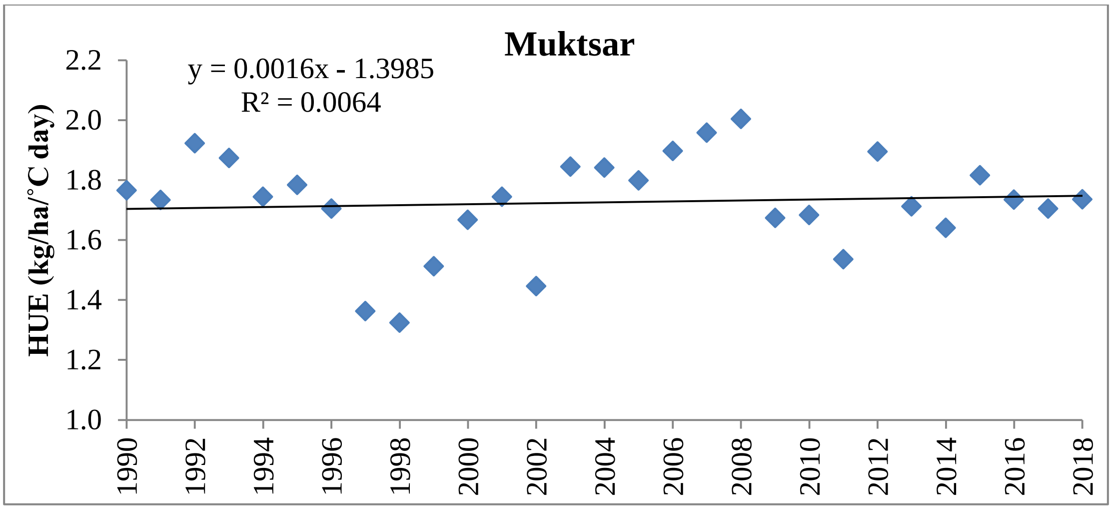


Fig 4.88: **Variability in heat use efficiency (HUE) of rice from 1990-2018 at Muktsar under transplanting window II**

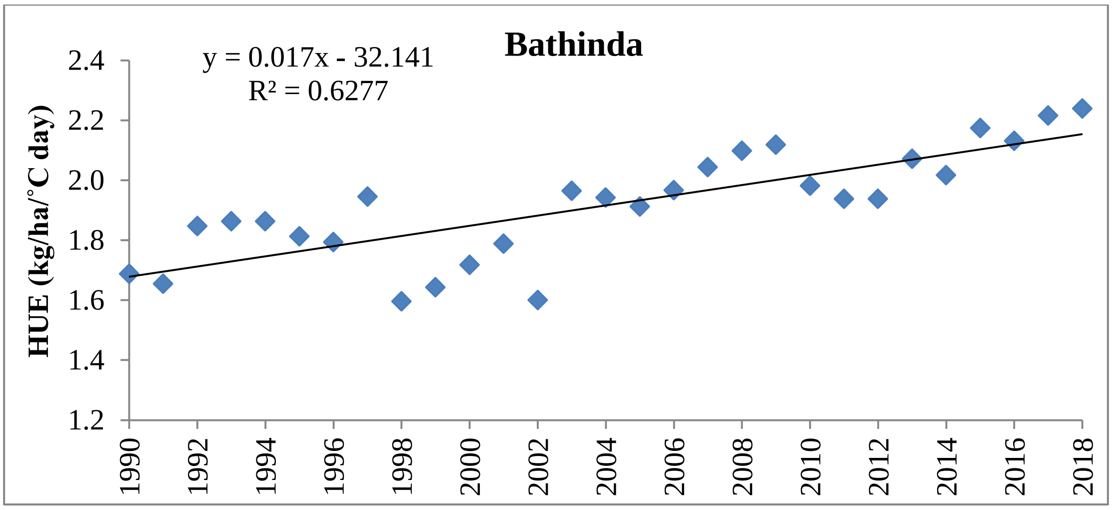


Fig 4.89: **Variability in heat use efficiency (HUE) of rice from 1990-2018 at Bathinda under transplanting window II**

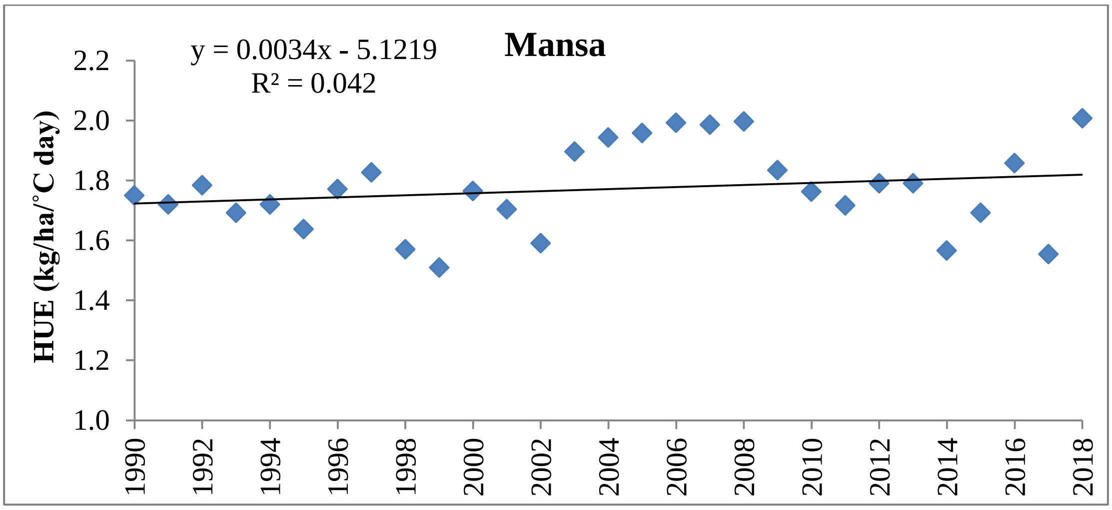


Fig 4.90 : **Variability in heat use efficiency (HUE) of rice from 1990-2018 at Mansa under transplanting window II**

4.2.7 Trend analysis of heat use efficiency of rice under transplanting window III

The data analysis from 1990-2018 for knowing increasing and decreasing trends in heat use efficiency (HUE**)** was carried out to observe variation during different time period. The results are presented in Fig 4.91 to 4.107.Variation in heat use efficiency was observed during different time period. It was observed that there was increasing trend of heat use efficiency (HUE**)** in Hoshiarpur, Kapurthala, Jalandhar, Ludhiana, Moga, Patiala, Sangrur, Firozpur, Bathinda. In Gurdaspur, SBS Nagar, Fategarh Sahib, Faridkot, Muktsar and Mansa no major trend was observed in the value of HUE in different year indicating less variation in HUE during different time period. The R^2 value was highest at Ludhiana (0.625) and lowest at S.B.S Nagar (0.002). The decreasing trend was observed in Rupnagar and Amritsar.Among all the districts the highest rate of AGDD increased was observed for Ludhiana (0.0202 kg/ha/ ºC day year^{-1}) followed by Bathinda (0.0175kg/ha/ºC day year^{-1}) and highest decreasing rate was observed for Rupnagar (-0.0043 kg/ha/ºC day year^{-1}) followed by Amritsar (-0.001 kg/ha/ ºC day year^{-1}). For Hoshiarpur, Kapurthala, Jalandhar, Moga, , Patiala, Sangrur, Firozpur, value of the rate of increase was 0.0061 kg/ha/ºC day year^{-1}, 0.0143kg/ha/ºC day year^{-1}, 0.006kg/ha/ºC day year^{-1}, 0.0113 kg/ha/ºC day year^{-1}, 0.0057kg/ha/ºC day year^{-1}, 0.0147kg/ha/ºC day year^{-}1, 0.0057kg/ha/ºC day year^{-1}.

In Gurdaspur, S.B.S.Nagar, Fatehgarh Sahib, Faridkot, Muktsar and Mansa the rate was 0.0012 kg/ha/ºC day year^{-1}, 0.0016kg/ha/ºC day year^{-1}, 0.0001kg/ha/ºC day year^{-1}, 0.0026kg/ha/ºC day year^{-1}, 0.0012kg/ha/ºC day year^{-1} and 0.0032kg/ha/ºC day year^{-1}.

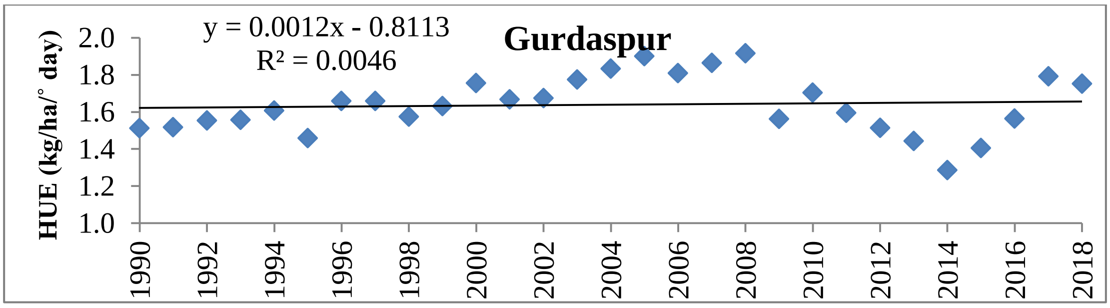


Fig 4.91 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Gurdaspur under transplanting window III

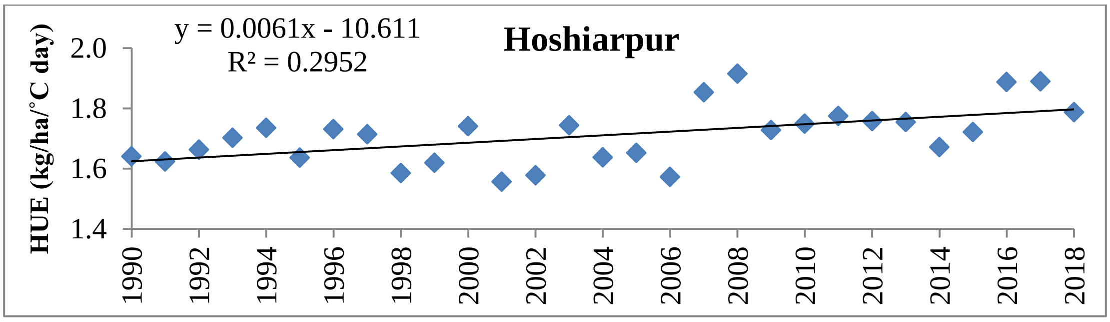


Fig 4.92 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Hoshiarpur under transplanting window III

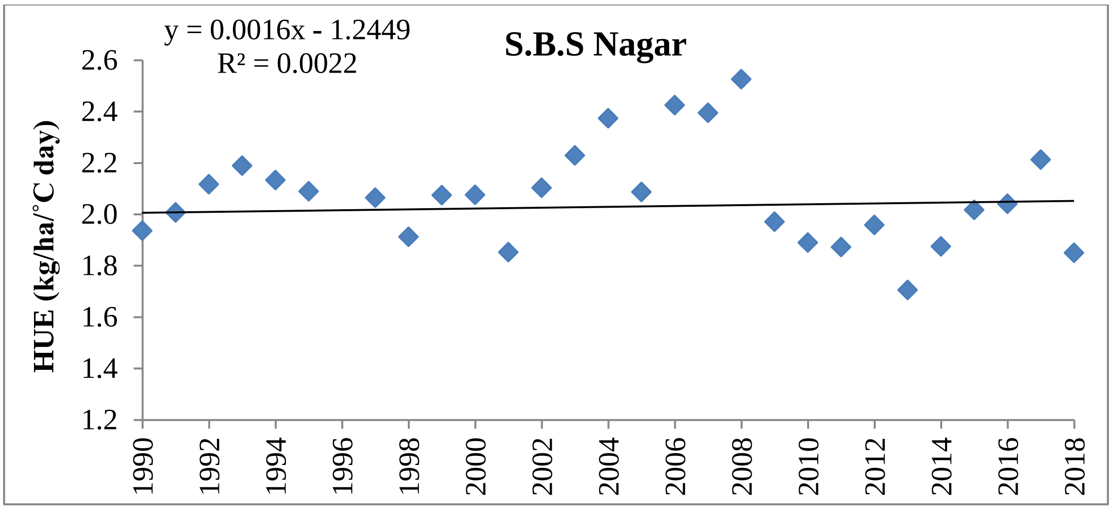


Fig 4.93 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at S.B.S Nagar under transplanting window III

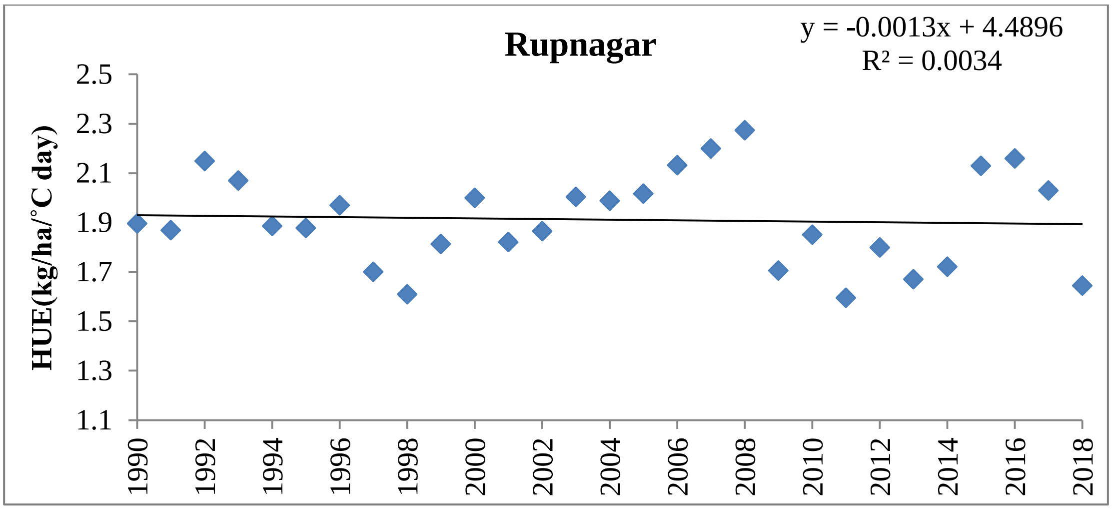


Fig 4.94 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Rupnagar under transplanting window III

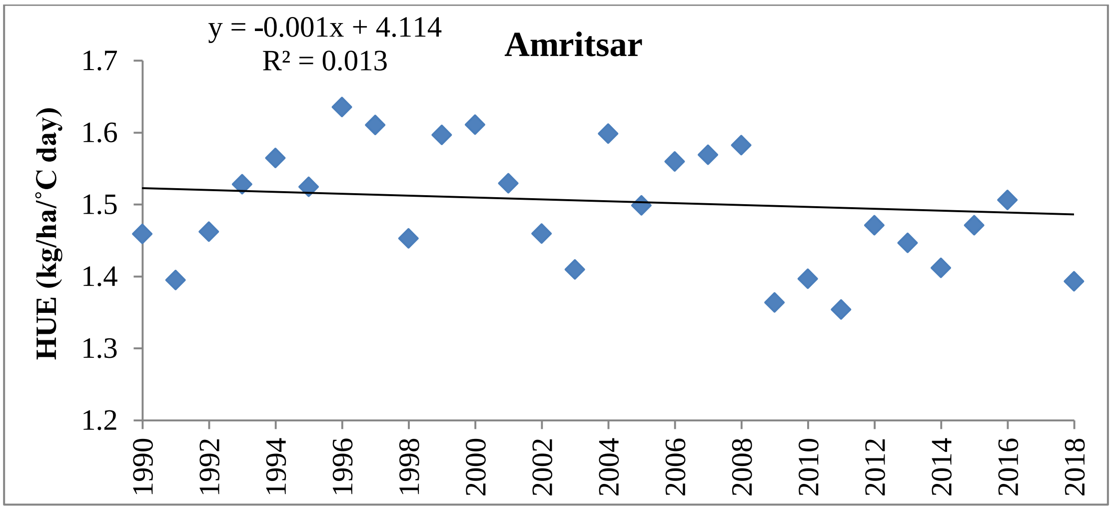


Fig 4.95 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Amritsar under transplanting window III

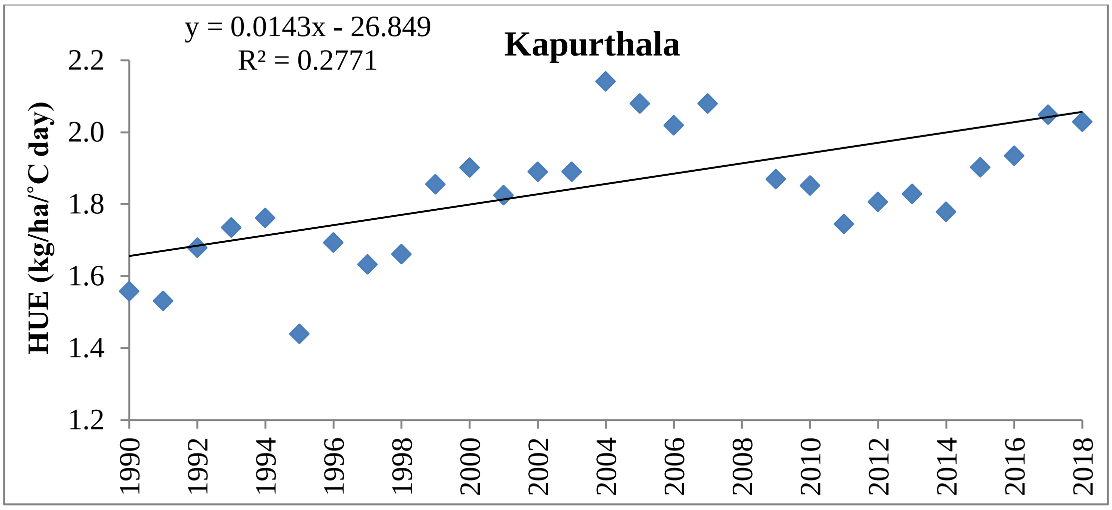


Fig 4.96 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Kapurthala under transplanting window III

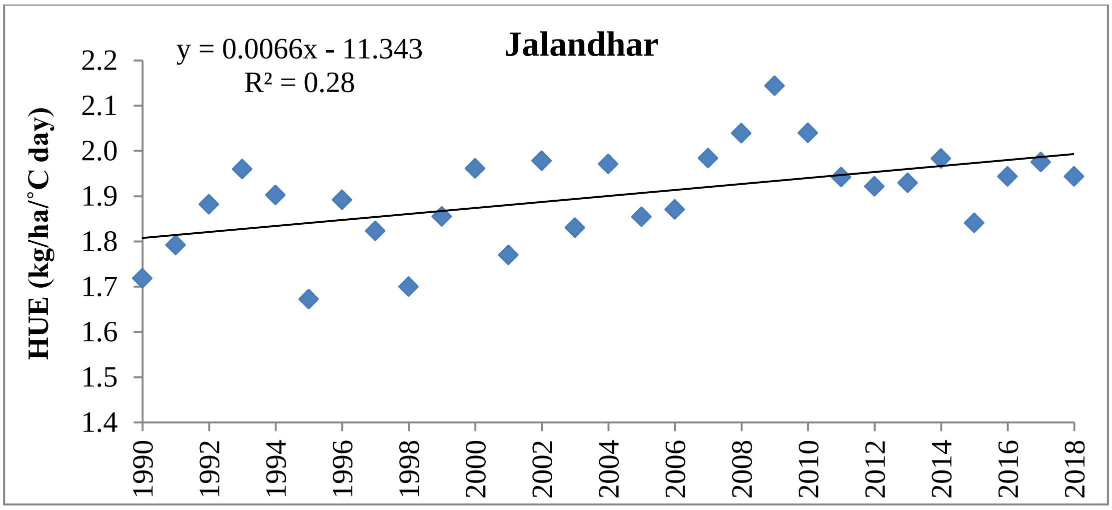


Fig 4.97 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Jalandhar under transplanting window III

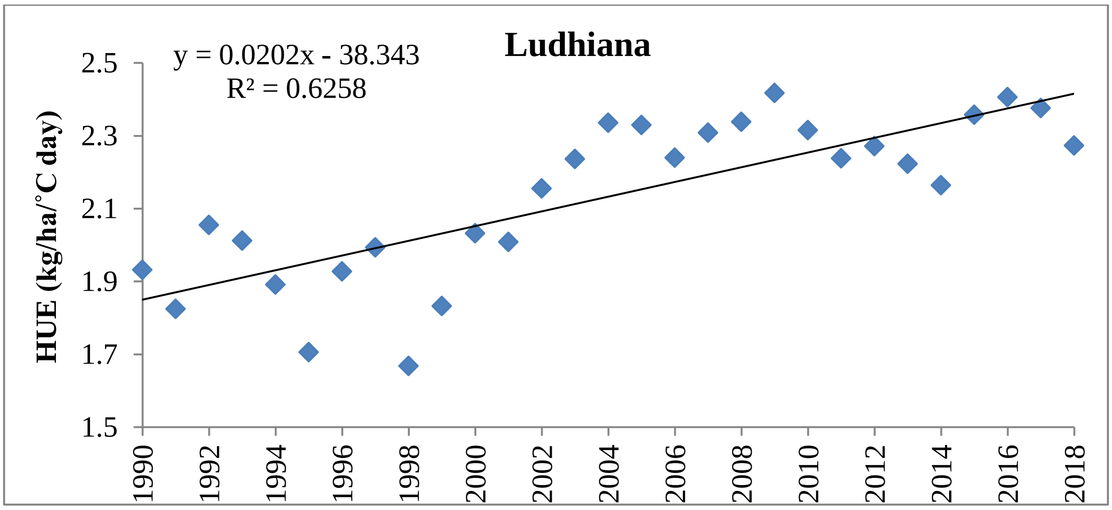


Fig 4.98 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Ludhiana under transplanting window III

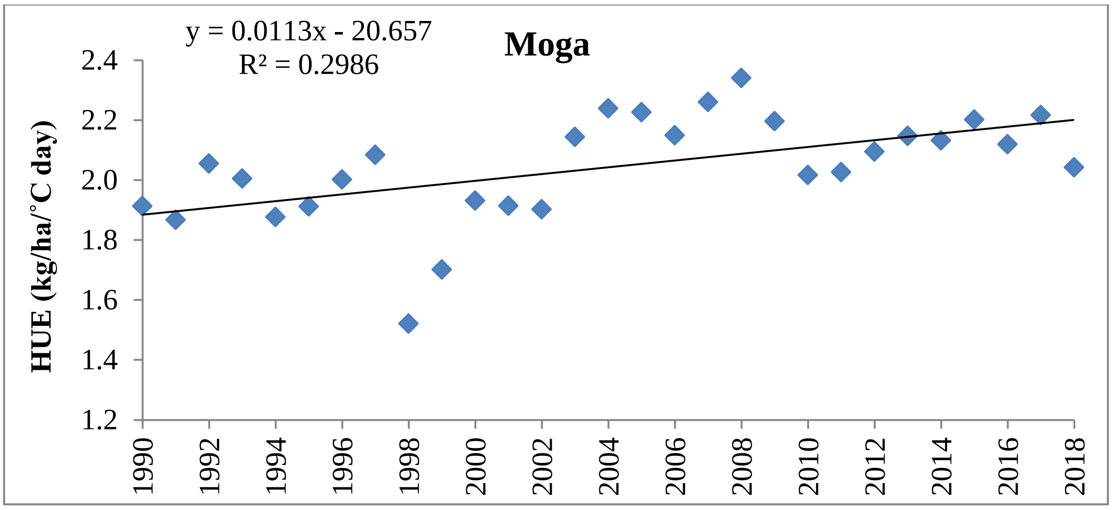


Fig 4.99 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Moga under transplanting window III

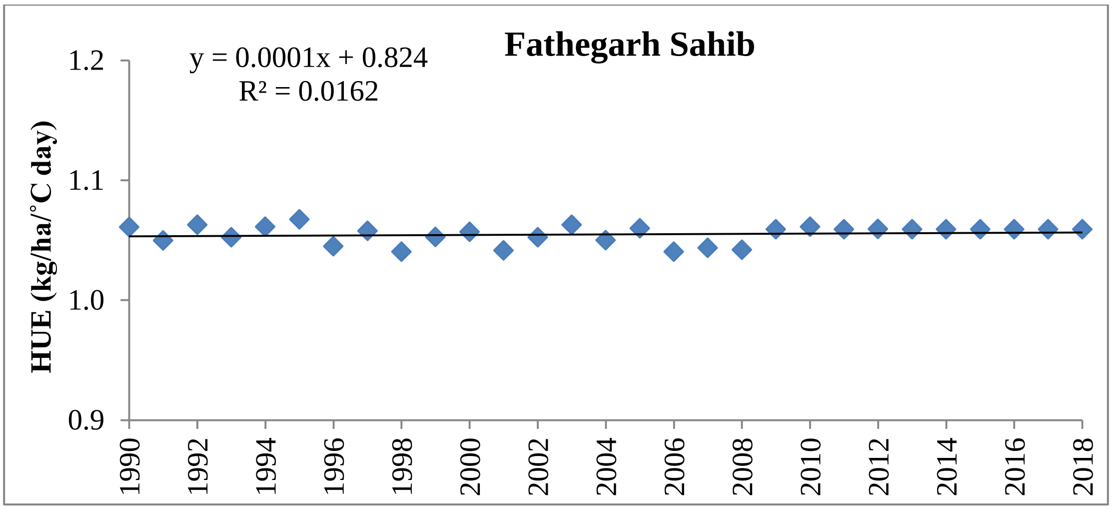


Fig 4.100 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Fatehgarh Sahib under transplanting window III

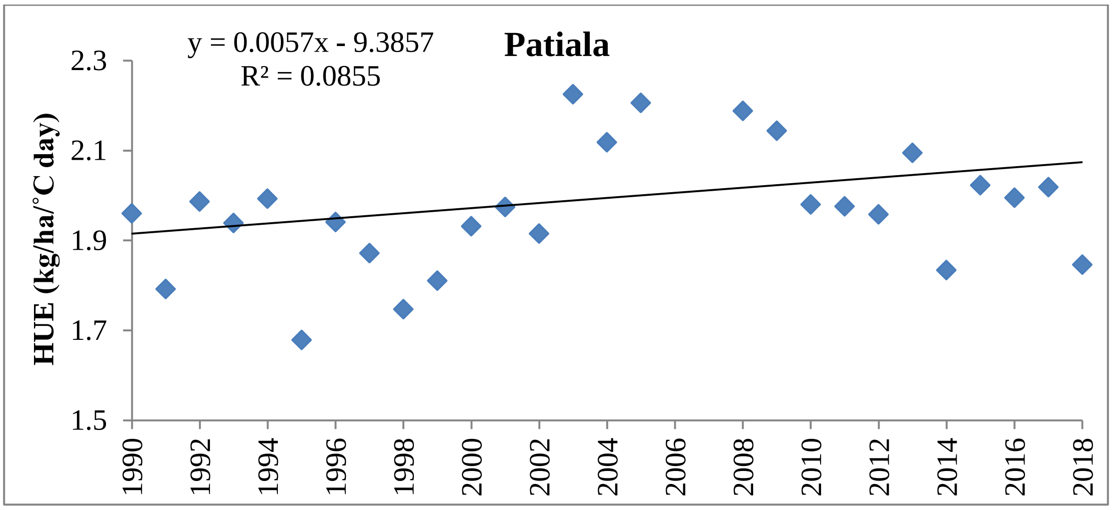


Fig 4.101 : Variability in heat use efficiency (HUE) of rice from 1990-2018 at Patialav under transplanting window III

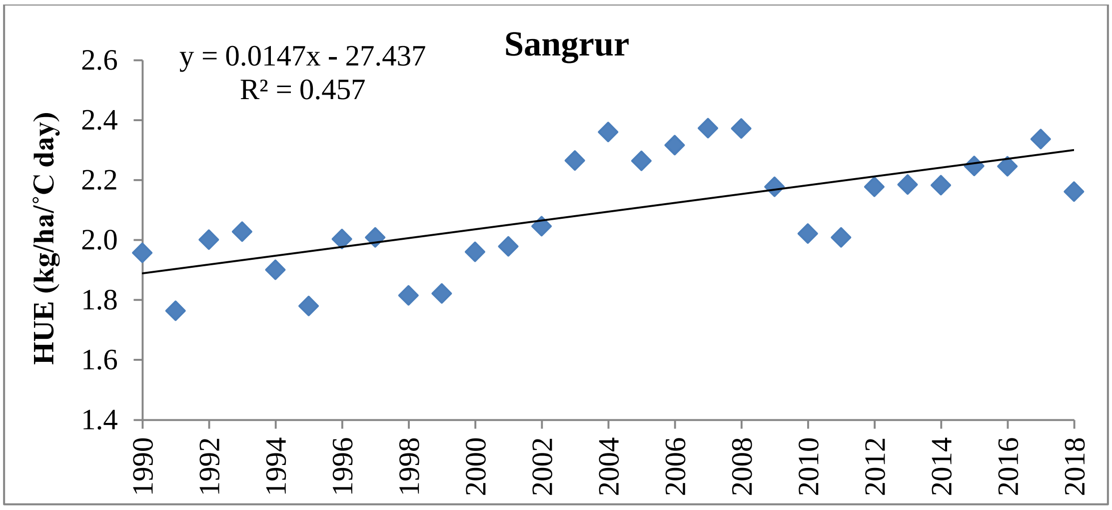


Fig 4.102 : **Variability in heat use efficiency (HUE) of rice from 1990-2018 at Sangrur under transplanting window III**

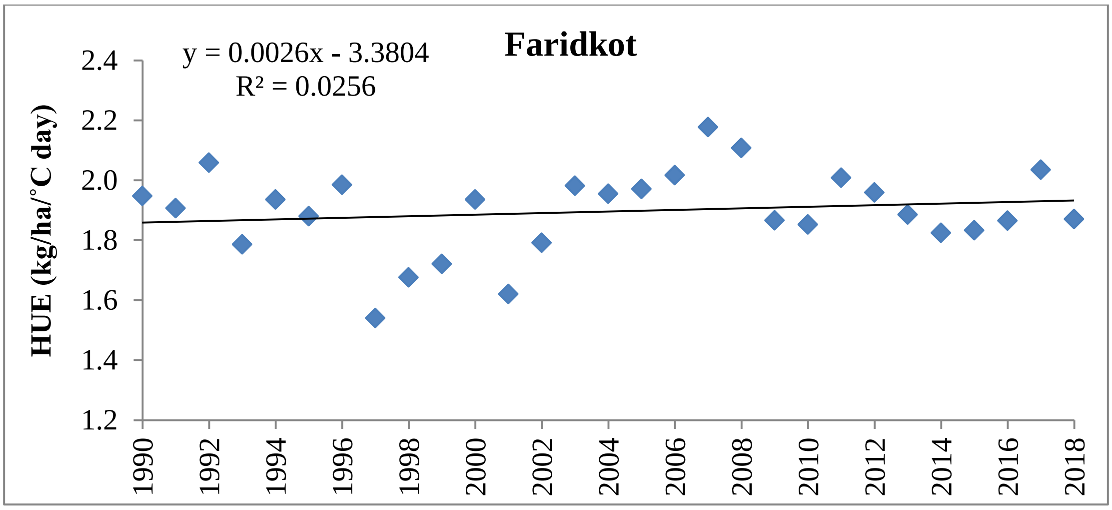


Fig 4.103 : **Variability in heat use efficiency (HUE) from 1990-2018 at Faridkot under transplanting window III**

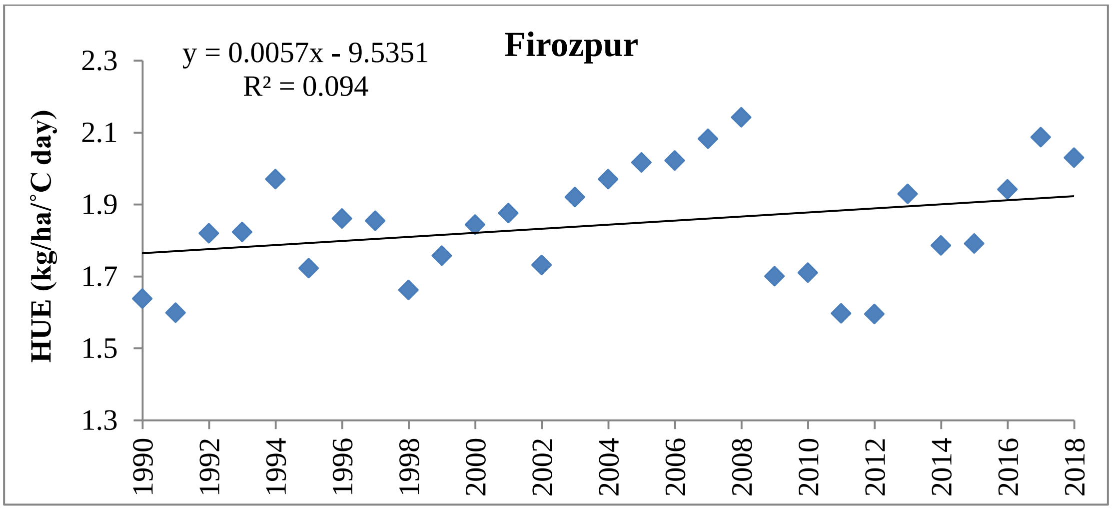


Fig 4.104: **Variability in heat use efficiency (HUE) of rice from 1990-2018 at Firozpur under transplanting window III**

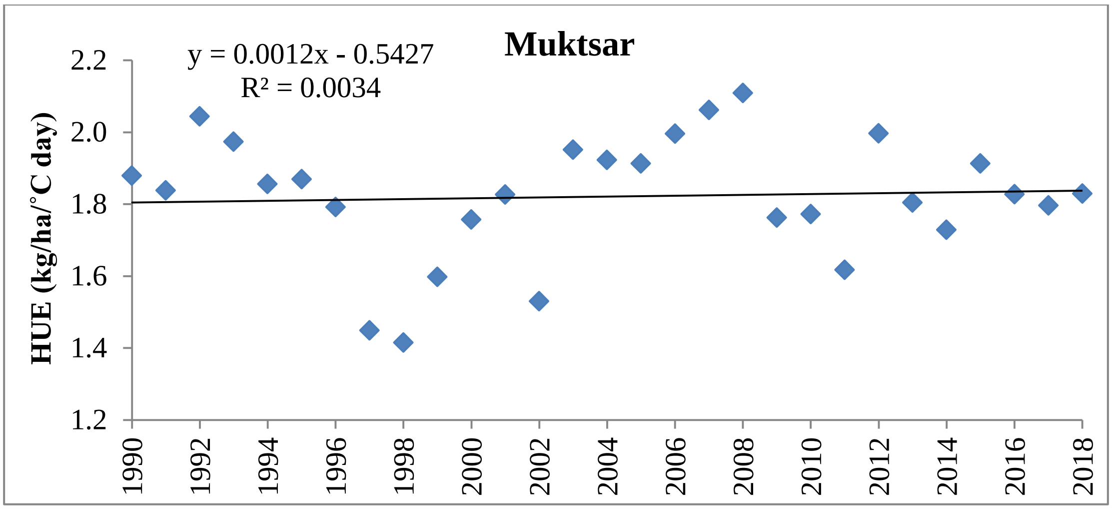


Fig 4.105 : **Variability in heat use efficiency (HUE) of rice from 1990-2018 at Muktsar under transplanting window III**

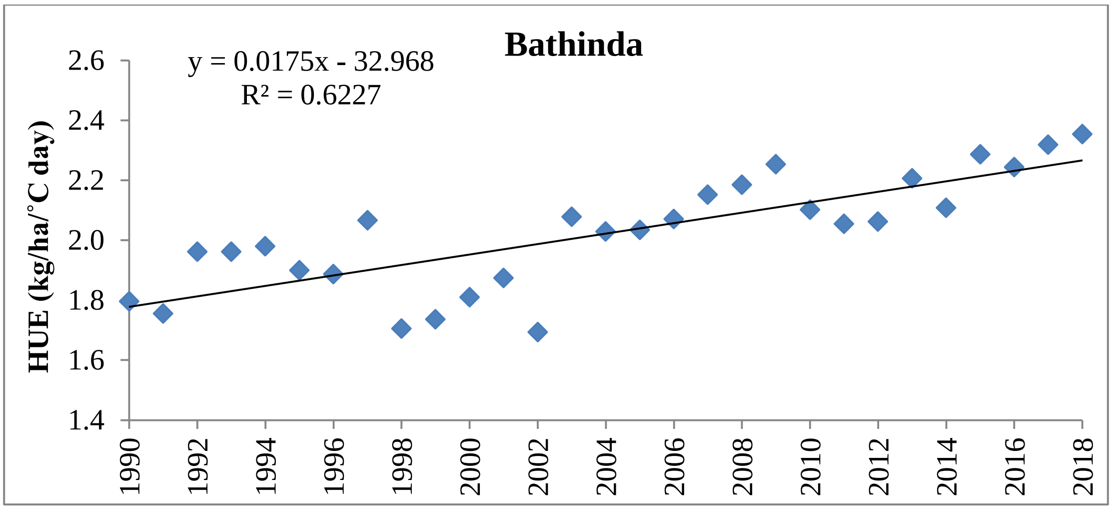


Fig 4.106 : **Variability in heat use efficiency (HUE) of rice from 1990-2018 at Muktsar under transplanting window III**

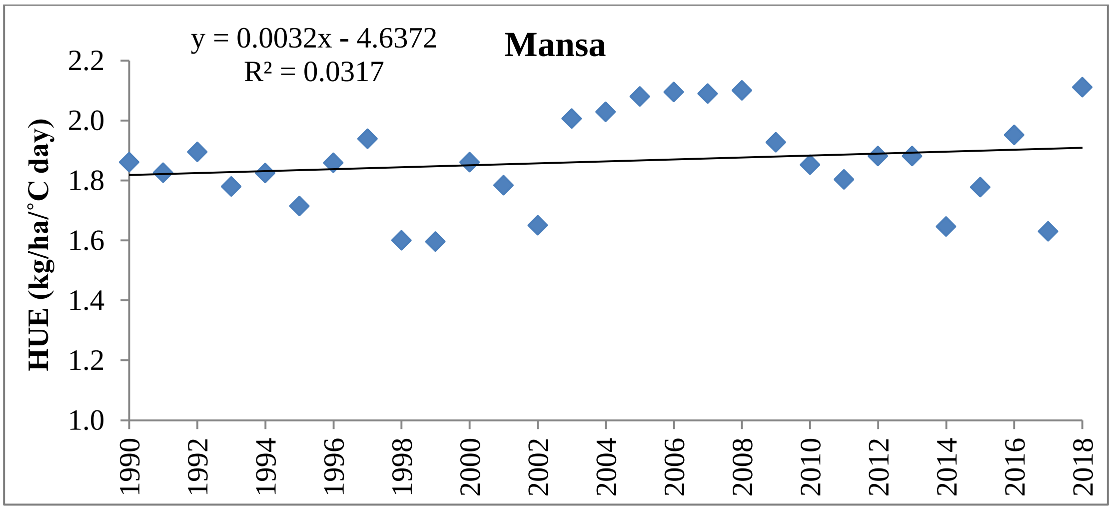


Fig 4.107 : **Variability in heat use efficiency (HUE) of rice from 1990-2018 at Mansa under transplanting window III**

4.2.8 Variability in heat use efficiency (HUE) of rice in Punjab during different pentad period in different transplanting windows

Variability in the heat use efficiency (HUE) of rice in different districts of Punjab was calculated for different pentads from 1990 to 2018 for different transplanting windows and presented in Figures 4.108, 4.109 and 4.110. It was found that maximum variability in HUE was during P4 (2005-2009) period and minimum variability during P2 (1995-1999) period under all transplanting windows.

Under transplanting window I, the value of HUE was 1.7 kg/ha/ºC day during P1 (1990-1994), P3 (2000-2004) and P5 (2010-2014). It was 1.6, 1.9 and 1.8 kg/ha/ºC day during P2 (1995-1999), P4 (2005-2009) and P6 (2015-2019). Under transplanting window II, the value of HUE was 1.7 kg/ha/ºC day during P1 (1990-1994) and P2 (1995-1999). It was 1.8 kg/ha/ºC during P3 (2000-2004) and P5 (2010-2014) and 1.9 kg/ha/ºC during P4 (2005-2009) and P6 (2015-2019). Under transplanting window III the value of HUE was 1.9 kg/ha/ºC day during P1 (1990-1994), P3 (2000-2004) and P5(2010-2014). It was 1.8 kg/ha/ºC during P2 (1995-1999), 2.1 kg/ha/ºC during P4 (2005-2009) and 2.0 kg/ha/ºC during P5 (2015-2019).

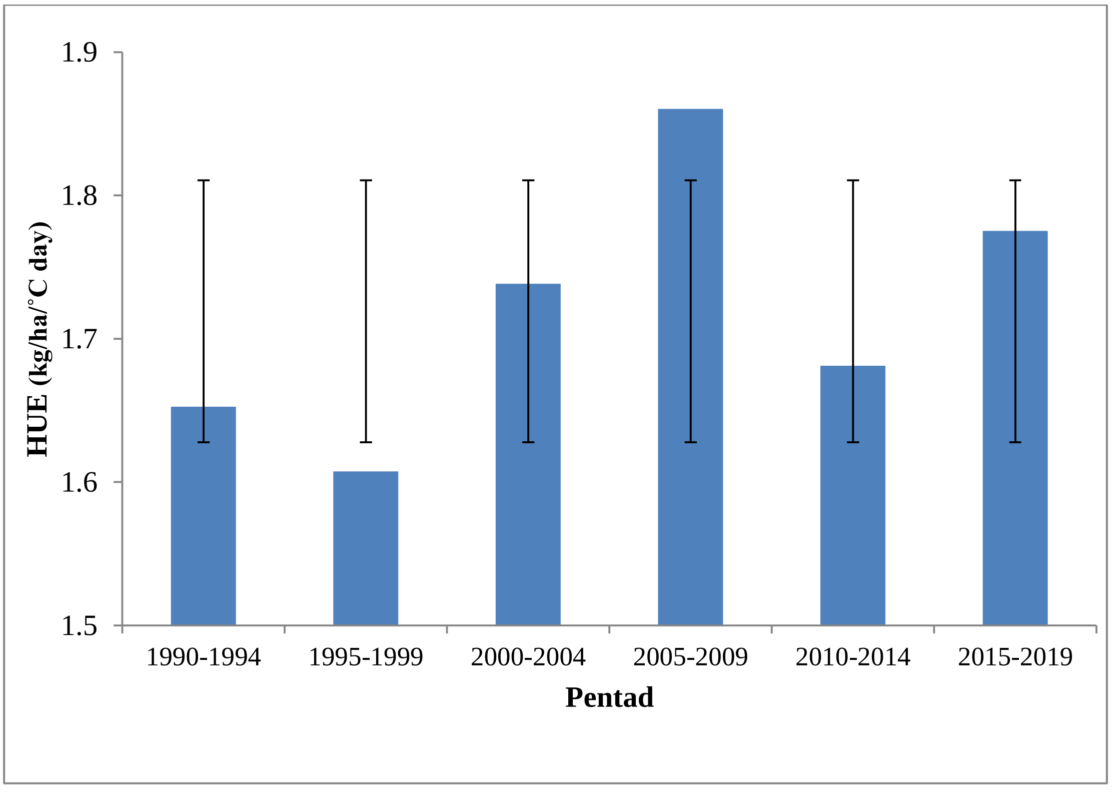


Fig. 4.108: Variation of heat use efficiency of rice in Punjab in transplanting window I (HUE pentad 2015 to 2019 include data from 2015 to 2018)

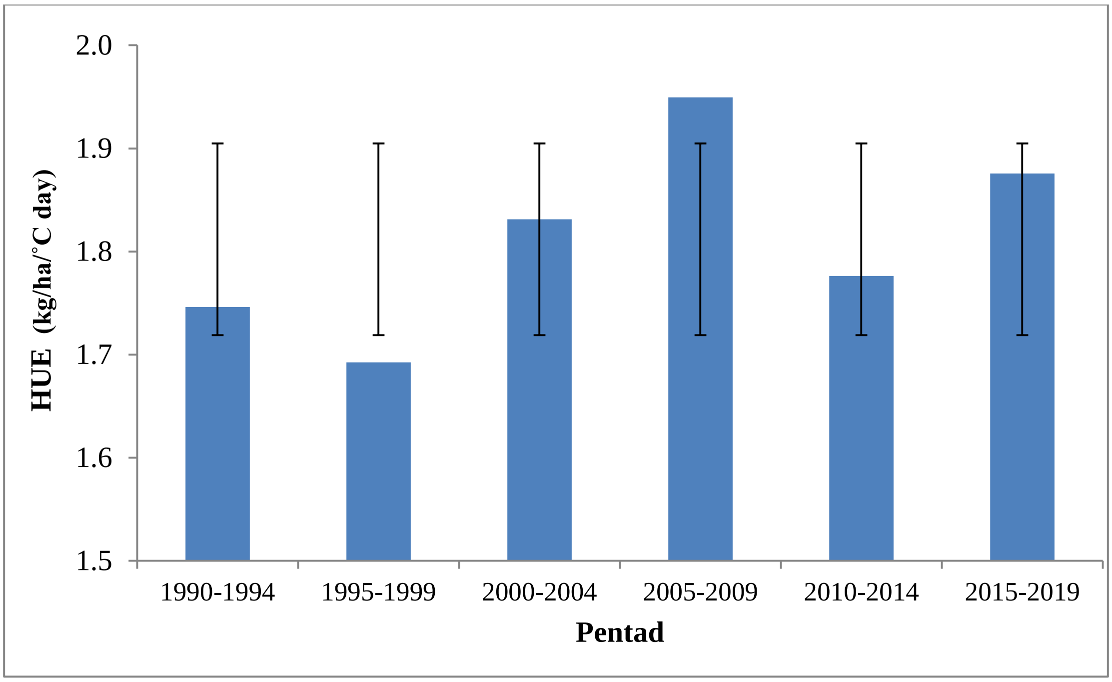


Fig. 4.109 :Variation of heat use efficiency of rice in Punjab in transplanting window II (HUE pentad 2015 to 2019 include data from 2015 to 2018)

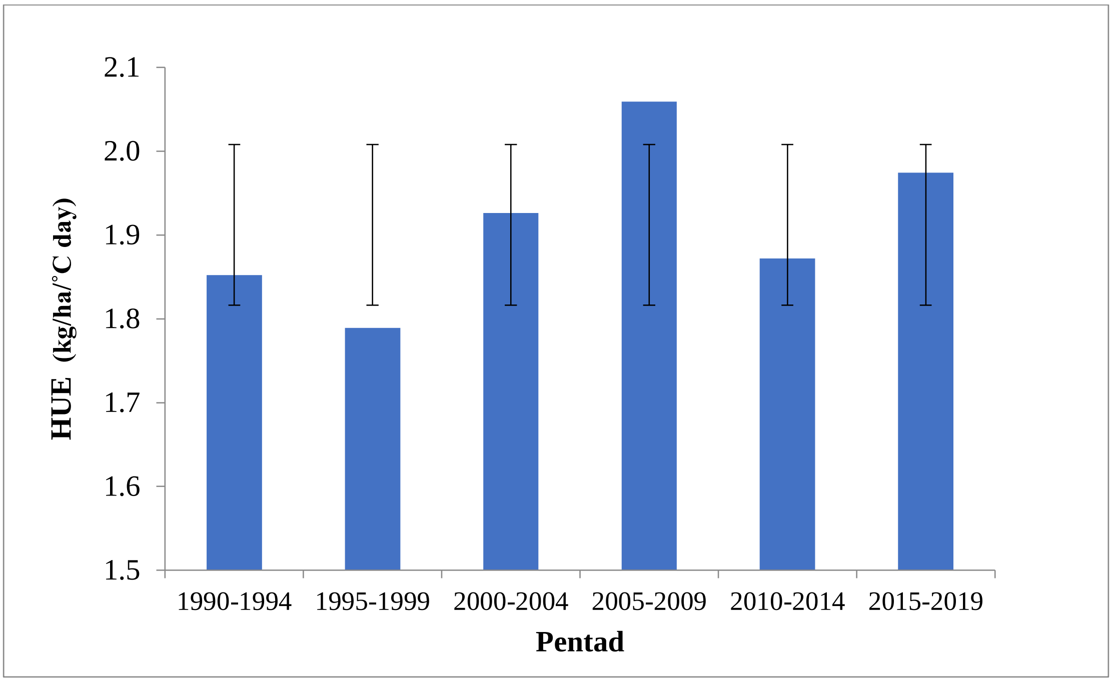


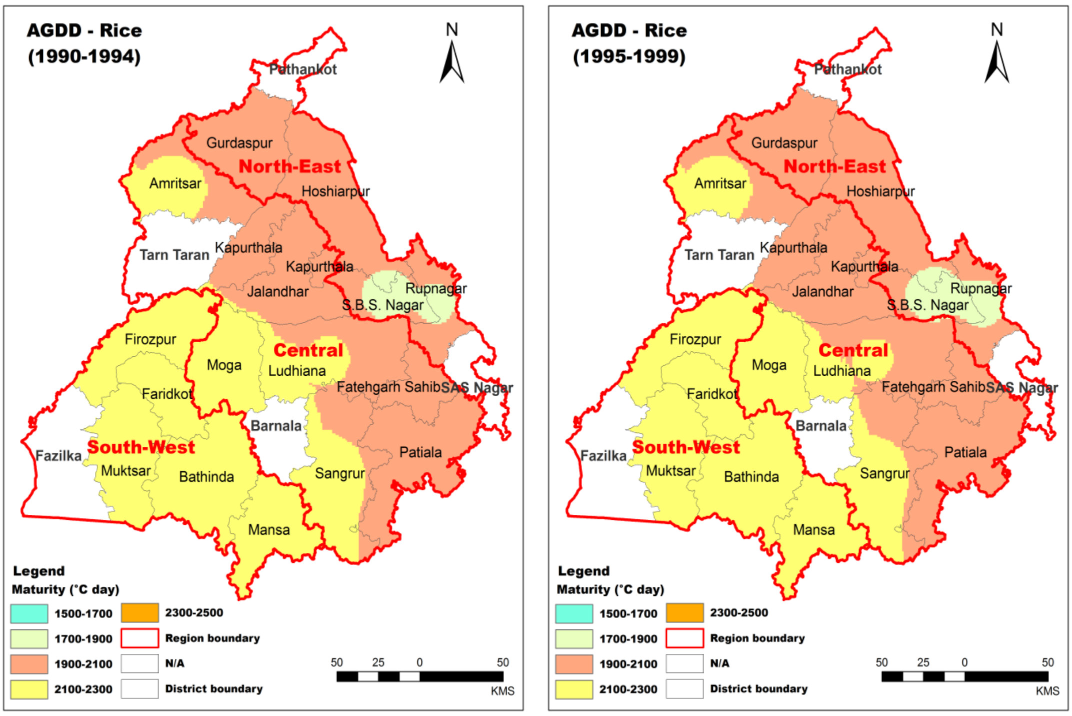
Fig.4.110: Variation of heat use efficiency of rice in Punjab in transplanting window III (HUE pentad 2015 to 2019 include data from 2015 to 2018)

4.3 SPATIO TEMPORAL VARIABILITY IN THERMAL REQUIREMENTS OF RICE IN PUNJAB USING GEOSPATIAL TECHNOLOGY

The spatio-temporal variation in thermal requirements of rice in Punjab under different transplanting windows was delineated by using Arc GIS 10.2. and are presented in Figures 4.111,4.112 and 4.113. However, data for Barnala, Fazilka, Pathankot, SAS Nagar and Tarn taran was not available (N/A).

4.3.1 Spatio temporal variability in thermal requirements of rice in under transplanting window I

The data from 1990 to 2019 was analysed pentad wise. In the North east region of Punjab during the period from 1990-1994 to 2010-2014 AGDD changed from 1900-2100 ºC day to 2100-2300 ºC day in Gurdaspur and Hoshiarpur district. In S.B.S. Nagar, major portion was under 1700-1900ºC day which changed to 2300-2500 ºC day in 2010-2014 period. In Rupnagar AGDD changed from 1900-2100 ºC day to 2300-2500 ºC day. In the central region of Punjab the major portion of Amritsar was under 2100-2300 ºC day in 1990-1994. In 2010-2014 the whole district showed the heat unit acccumulation of 2100-2300ºC day. Whereas, in Moga and Sangrur heat unit accumulation changed from 2100-2300 ºC day to 2300-2500 ºC day. During the same time period in major portion of Ludhiana, Patiala, Kapurthala, Jalandhar AGDD changed from 1900-2100 to 2100-2300ºC day and in Fatehgarh Sahib from 1900-2100 to 2300-2500 ºC day. In the South West region mainly in Faridkot, Firozpur, Mansa, Muktsar and Bathinda, heat unit accumulation changed from 2100-2300ºC to 2300-2500ºC day during same time period. During the period from 2015-2019 AGDD value in whole state lied between 2300-2500ºC day except Ludhiana and Bathinda (2100-2300ºC day).



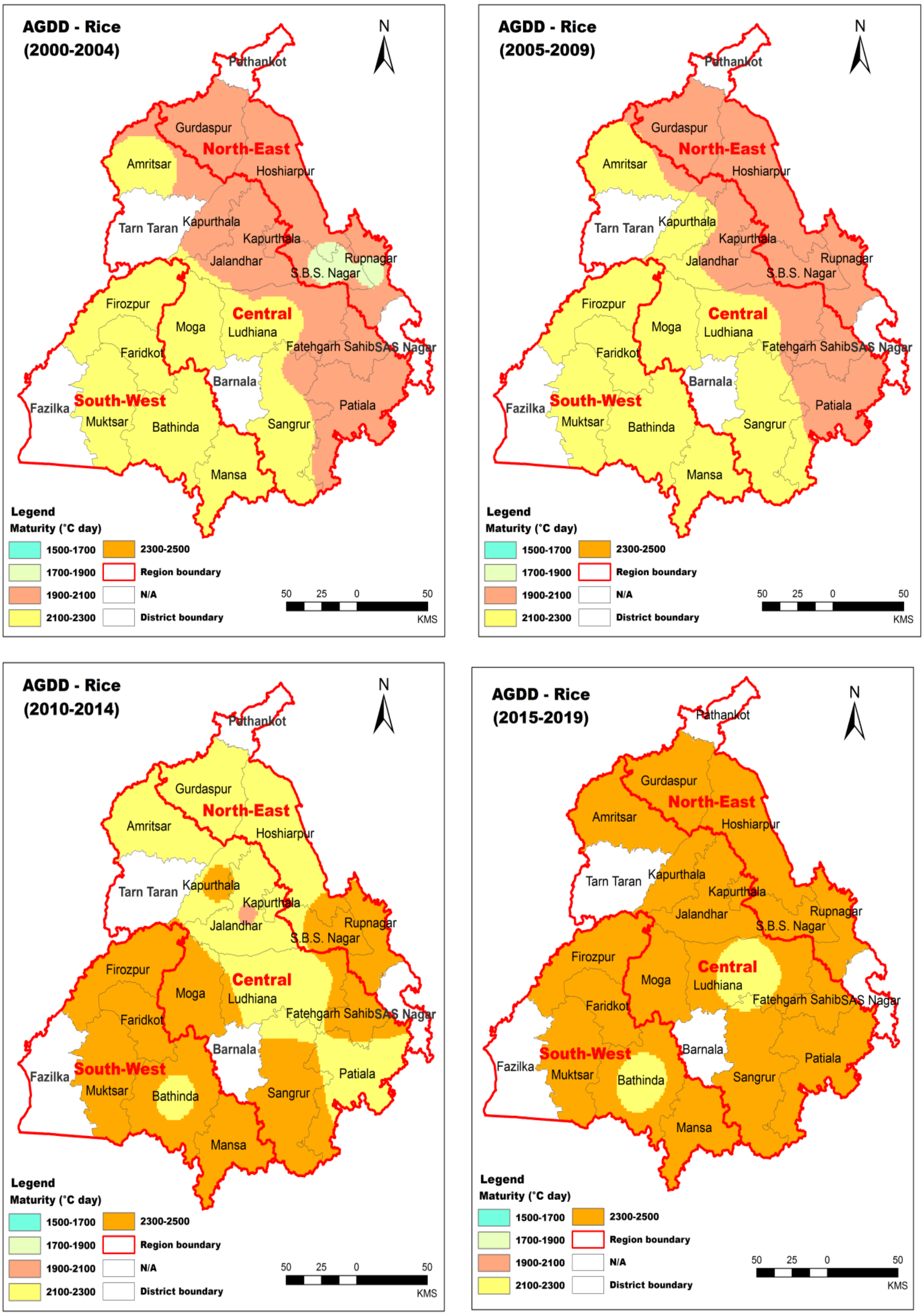
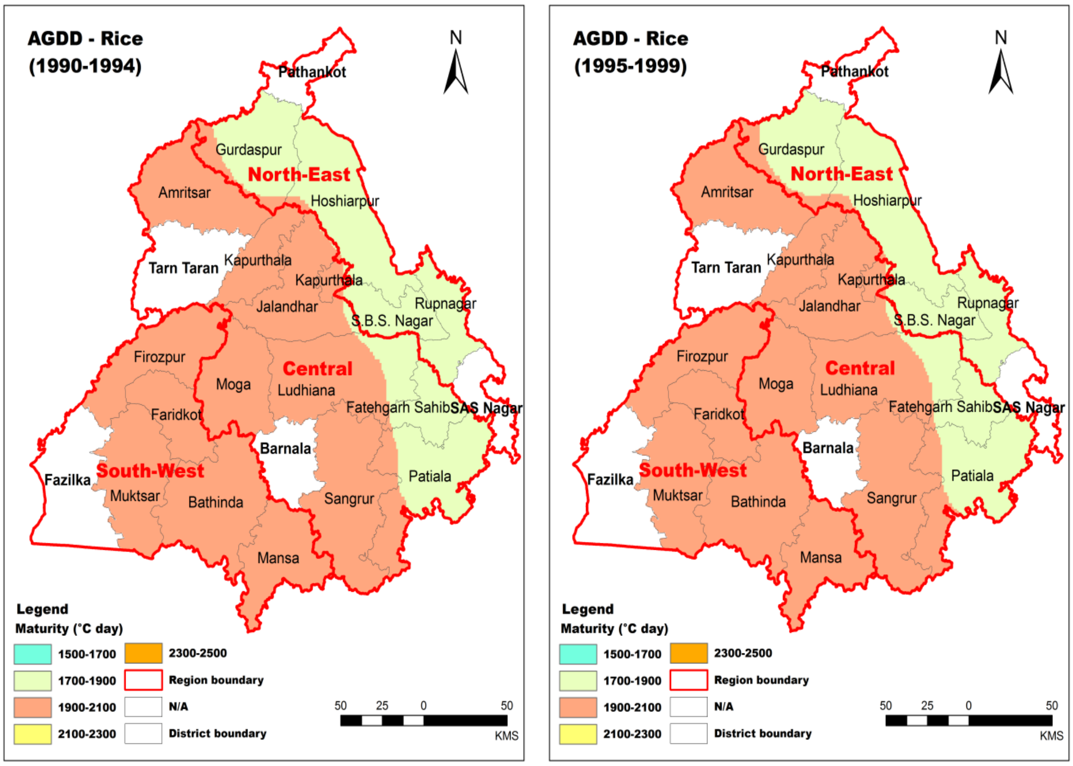


Fig 4.111 : **Spatio-temporal variability in AGDD from 1990 to 2019 in different districts of Punjab under transplanting window I**

4.3.2 Spatio temporal variability in thermal requirements of rice in under transplanting window II

In the north east districts during 1990-1994 to 2015-2019 the AGDD changed from 1700-1900 ºC day to 2100-2300ºC day. In central region during same time period AGDD changed from 1900-2100 to 2100-2300ºC day in Amritsar, major portion of Ludhiana, Kaputhala, Jalandhar, Moga and Sangrur. The AGDD in district Fatehgarh Sahib and Patiala changed from 1700-1900ºC day to 2100-2300ºC day. In south-west districts, heat unit accumulation changed from 1900-2100 to 2100-2300ºC day from 1990-1994 to 2015-2019 except in some portion of Mansa, Muktsar and Faridkot where it changed to 2300-2500ºC day.



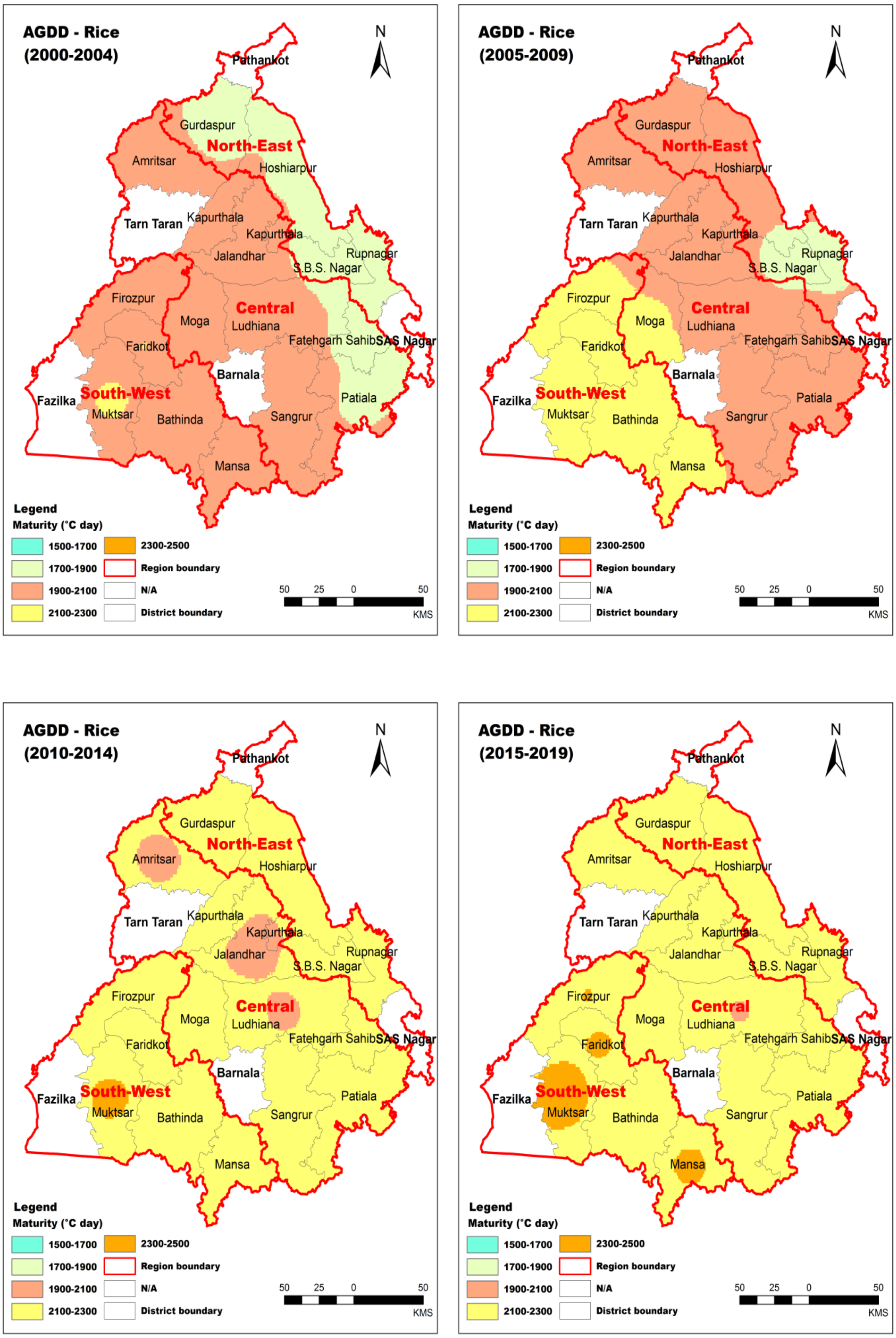
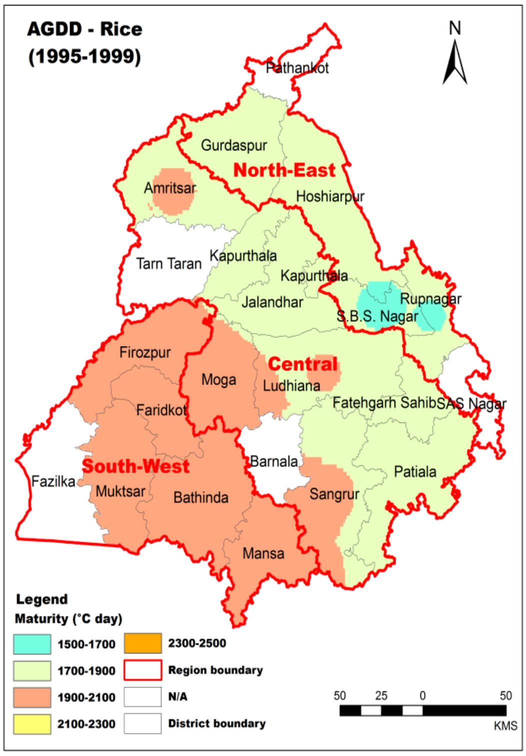


Fig 4.112 : Spatio-temporal variability in AGDD from 1990 to 2019 in different districts of Punjab under transplanting window II

4.3.3 Spatio temporal variability in thermal requirements of rice in under sowing window III

Under transplanting window III, from 1990-1994 to 2010-2014 in the north east districts, Gurdaspur and Hoshiarpur, and major portion Rupnagar AGDD changed from 1700-1900 ºC day to 1900-2100ºC day. However, in major portion of S.B.S. Nagar the heat unit accumulation changed from 1500-1900ºC day to 1900-2100ºC day. In central region, during the same period AGDD shift from 1700-1900ºC day to 1900-2100ºC day in Amritsar, Kapurthala, Jalandhar, Ludhiana, Fatehgarh Sahib and Patiala. However, in Moga AGDD vary from 1900-2100 to 2100-2300ºC day and in major portion of Sangrur the AGDD vary from 1700-1900 to 2100-2300. In the South west region, in all districts AGDD vary from 1900-2100 to 2100-2300ºC day except in Bathinda where AGDD remain 1900-2100 ºC day. During 2015-2019 period in whole north-east, central and south-west districts, AGDD changed to 2100-2300ºC day except in Ludhiana, Bathinda , Amritsar, Gurdaspur and Hoshiarpur where AGDD remained 1900-2100ºC day.



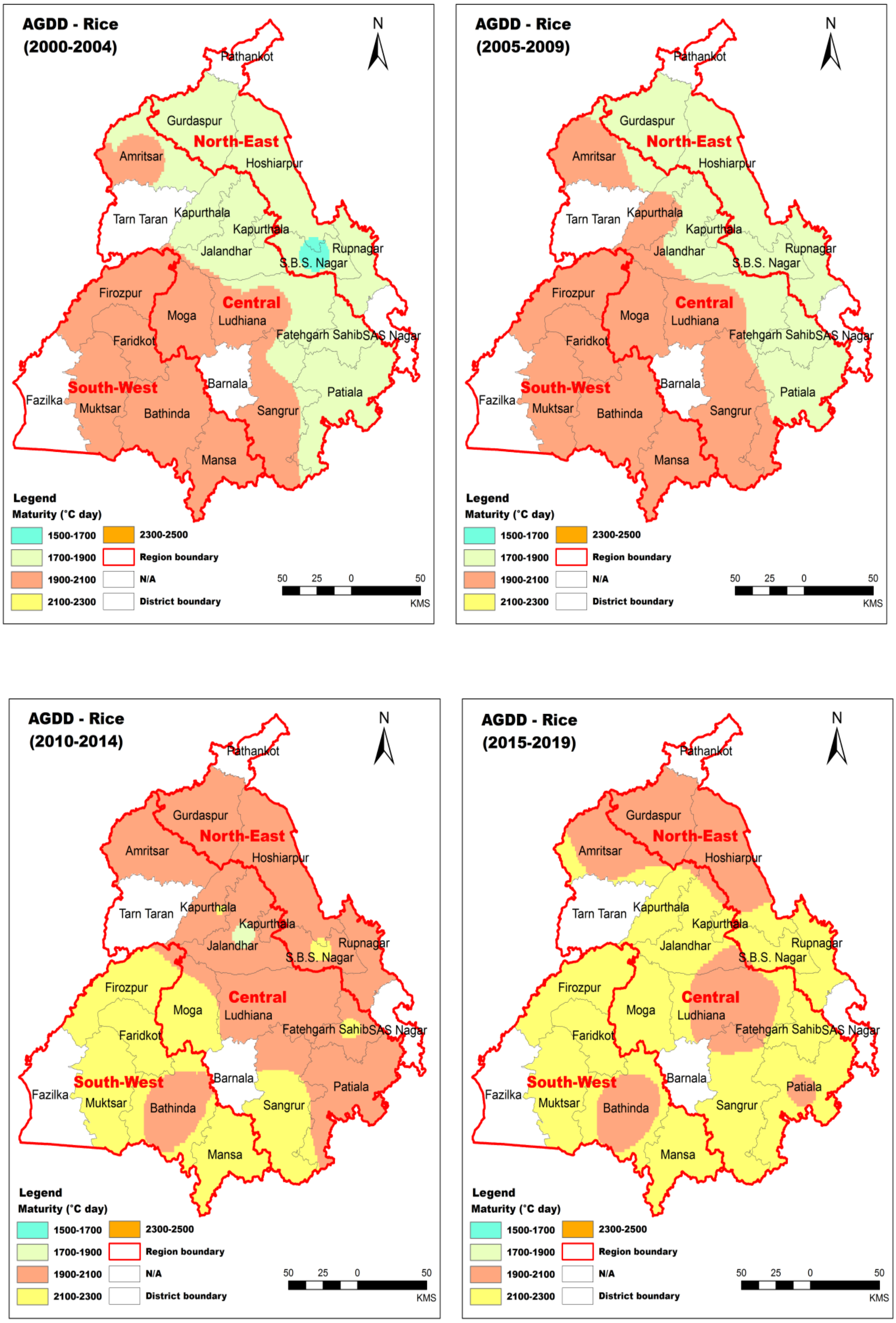


Fig 4.113 : Spatio-temporal variability in AGDD from 1990 to 2019 in different districts of Punjab under transplanting window III

4.4 VALIDATION OF HISTORICAL THERMAL REQUIREMENTS WITH ACTUAL EXPERIMENTAL DATA UNDER STAGGERED TRANSPLANTING

Pentad wise variability in thermal requirements of rice was analyzed for three crop stages i.e. maximum tillering, anthesis and physiological maturity and is presented in Tables from 4.23 to 4.39. The historical data was compared with experimental accumulated heat units for calculating deviation per cent. The following results were obtained:

a) Under transplanting window I, the maximum positive deviation (%) in AGDD at maximum tillering (18.15), anthesis (18.50) and physiological maturity (20.51) was during the P3 (2000-2004) period, P2 (19995-1999), P2 (1995-1999) respectively in S.B.S Nagar district followed by Rupnagar. The most negative deviation (%) in AGDD at maximum tillering (-12.68), anthesis (-12.07) and physiological maturity (-10.25) was observed during P6 (2015-2019) for Muktsar district.

b) Under Transplanting window II, the most positive deviation (%) in AGDD at maximum tillering (25.57) was observed at Hoshiarpur district during P3(2000-2004) and at anthesis (20.12) and physiological maturity (20.94) during P2 (19995-1999) at S.B.S Nagar followed by Rupnagar. The deviation (%) was most negative at maximum tillering (- 9.60), anthesis (- 9.96) and physiological maturity (- 9.58) during the pentad P6 (2015-2019) from Muktsar.

c) Under Transplanting window III, the most positive deviation (%) in AGDD at maximum tillering (18.19), anthesis (20.56) and physiological maturity (21.01) was found during the period of P1(1990-1994), P2 (19995-1999), P1(1990-1994) respectively in S.B.S. Nagar district followed by Rupnagar. The deviation (%) was most negative at maximum tillering (-9.46), anthesis (- 9.58) and physiological maturity (- 10.19) during the pentad P6 (2015-2019) for Muktsar.

Table 4.23: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Gurdaspur

Gurdaspur							
Pentad	Phenological Stages	Transplanting Window I (13 June)		Transplanting Window II (21 June)		Transplanting Window III (29 June)	
		AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)
P1 (1990-94)	Maximum Tillering	668.81	12.92	739.47	14.73	720.93	14.31
	Anthesis	1370	13.93	1372.32	14.77	1307.27	16.10
	Physiological Maturity	1906.68	16.28	1806	16.93	1700.61	17.08
P2 (1995-99)	Maximum Tillering	668.81	13.26	743.82	14.06	728.85	13.07
	Anthesis	1364.97	14.35	1360.02	15.81	1306.65	16.16
	Physiological Maturity	1905.01	16.38	1810.43	16.64	1712.24	16.28
P3 (2000-04)	Maximum Tillering	666.67	13.29	743.76	14.07	732.83	12.45
	Anthesis	1376.24	13.41	1377.66	14.32	1328.05	14.28
	Physiological Maturity	1918.37	15.57	1819.56	16.06	1727.62	15.25
P4 (2005-09)	Maximum Tillering	687.875	9.79	772.565	9.82	749.455	9.96
	Anthesis	1438.04	8.54	1438.275	9.51	1374.685	10.41
	Physiological Maturity	2001.73	10.76	1907.215	10.72	1789.055	11.29
P5 (2010-14)	Maximum Tillering	816.06	-7.45	873.84	-2.91	840.8	-1.99
	Anthesis	1644.77	-5.11	1610.02	-2.18	1540.38	-1.47
	Physiological Maturity	2289.77	-3.17	2157.79	-2.13	2028.84	-1.86
P6 (2015-19)	Maximum Tillering	824.76	-8.43	883.06	-3.92	849.5	-2.99
	Anthesis	1661.57	-6.06	1627.49	-3.23	1556.71	-2.50
	Physiological Maturity	2315.83	-4.26	2182.29	-3.23	2062.29	-3.46

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.24: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Hoshiarpur

Hoshiarpur							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
P1 (1990-94)	Maximum Tillering	698.23	8.17	675.89	25.52	747.51	10.25
	Anthesis	1423.86	9.62	1404.86	12.11	1354.87	12.02
	Physiological Maturity	1984.03	11.75	1878.35	12.43	1769.78	12.50
P2 (1995-99)	Maximum Tillering	694.33	8.77	679.68	24.82	753.52	9.37
	Anthesis	1415.09	10.30	1390.43	13.27	1351.6	12.29
	Physiological Maturity	1979.34	12.01	1879.87	12.34	1778.16	11.97
P3 (2000-04)	Maximum Tillering	690.27	9.41	675.64	25.57	756.34	8.96
	Anthesis	1422.03	9.76	1404.38	12.15	1370.75	10.72
	Physiological Maturity	1985.98	11.64	1884.23	12.08	1789.7	11.25
P4 (2005-09)	Maximum Tillering	704.74	7.17	694.56	22.15	762.69	8.05
	Anthesis	1460.7	6.85	1440.8	9.31	1395.59	8.75
	Physiological Maturity	2040.56	8.65	1943.59	8.65	1837.29	8.37
P5 (2010-14)	Maximum Tillering	809.42	-6.69	769.72	11.39	835.55	-1.37
	Anthesis	1640.12	-4.84	1601.66	-0.78	1540.78	-1.49
	Physiological Maturity	2284.86	-2.97	2176.98	-2.03	2050.24	-2.89
P6 (2015-19)	Maximum Tillering	818.05	-7.68	769.72	10.22	843.39	-2.29
	Anthesis	1654.76	-5.68	1601.66	-1.66	1554.44	-2.36
	Physiological Maturity	2307.36	-3.91	2176.98	-3.00	2069.44	-3.79

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.25: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at S.B.S Nagar

S.B.S. Nagar							
Pentad	Phenological Stages	Transplanting Window I (13 June)		Transplanting Window II (21 June)		Transplanting Window III (29 June)	
		AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)
P1 (1990-94)	Maximum Tillering	649.28	16.32	715.91	18.51	697.24	18.19
	Anthesis	1326.77	17.64	1325.96	18.78	1262.41	20.23
	Physiological Maturity	1844.35	20.21	1746.19	20.94	1645.33	21.01
P2 (1995-99)	Maximum Tillering	644.25	17.23	717.88	18.18	702.82	17.26
	Anthesis	1317.17	18.50	1311.23	20.12	1258.88	20.56
	Physiological Maturity	1839.75	20.51	1748.06	20.81	1653.56	20.41
P3 (2000-04)	Maximum Tillering	639.23	18.15	714.47	18.75	704.83	16.92
	Anthesis	1321.24	18.13	1323.17	19.03	1276.05	18.94
	Physiological Maturity	1843.01	20.30	1749.58	20.70	1662.73	19.74
P4 (2005-09)	Maximum Tillering	667.77	13.10	748.815	13.30	720.89	14.32
	Anthesis	1371.41	13.81	1367.64	15.16	1308.86	15.96
	Physiological Maturity	1920.07	15.47	1828.53	15.49	1729.61	15.11
P5 (2010-14)	Maximum Tillering	824.08	-8.35	885.7	-4.21	856.36	-3.77
	Anthesis	1675.69	-6.86	1647.78	-4.42	1581.65	-4.04
	Physiological Maturity	2344.7	-5.44	2212.33	-4.55	2109.66	-5.62
P6 (2015-19)	Maximum Tillering	831.95	-9.22	894.85	-5.19	864.52	-4.68
	Anthesis	1689.75	-7.63	1662.35	-5.25	1595.01	-4.84
	Physiological Maturity	2364.85	-6.25	2232.26	-5.40	2128.05	-6.44

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.26: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Rupnagar

Rupnagar							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
P1 (1990-94)	Maximum Tillering	665.67	13.46	731.24	16.02	711.42	15.84
	Anthesis	1356.8	15.04	1352.36	16.46	1287.96	17.84
	Physiological Maturity	1885.92	17.56	1784.36	18.35	1682.37	18.35
P2 (1995-99)	Maximum Tillering	657.04	14.95	732.37	15.84	716.84	14.96
	Anthesis	1344.65	16.07	1338.83	17.64	1284.73	18.14
	Physiological Maturity	1880.93	17.87	1787.24	18.16	1690.96	17.74
P3 (2000-04)	Maximum Tillering	651.87	15.86	729.86	16.24	721.72	14.19
	Anthesis	1350.44	15.58	1352.67	16.44	1305.77	16.23
	Physiological Maturity	1888.29	17.41	1793.78	17.73	1706.95	16.64
P4 (2005-09)	Maximum Tillering	676.345	11.67	758.975	11.78	735.325	12.07
	Anthesis	1404.345	11.14	1403.11	12.25	1346.02	12.76
	Physiological Maturity	1968.41	12.63	1875.31	12.61	1777.12	12.04
P5 (2010-14)	Maximum Tillering	817.08	-7.57	877.79	-3.35	845.47	-2.53
	Anthesis	1661.29	-6.05	1634.51	-3.64	1566.64	-3.12
	Physiological Maturity	2327.39	-4.74	2196.68	-3.87	2091.24	-4.79
P6 (2015-19)	Maximum Tillering	821.52	-8.07	880.69	-3.67	847.85	-2.80
	Anthesis	1669.26	-6.50	1642.69	-4.12	1574.98	-3.63
	Physiological Maturity	2342.55	-5.36	2210.76	-4.48	2104.87	-5.41

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.27: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Amritsar

Amritsar							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
P1 (1990-94)	Maximum Tillering	751.65	0.48	826.82	2.61	804.08	2.49
	Anthesis	1531.28	1.93	1529.66	2.96	1456.82	4.18
	Physiological Maturity	2135.36	3.83	2021.82	4.45	1905.09	4.51
P2 (1995-99)	Maximum Tillering	749.49	0.77	831.05	2.09	811.45	1.56
	Anthesis	1526.09	2.27	1518.06	3.75	1457.85	4.11
	Physiological Maturity	2136.34	3.78	2028.94	4.08	1919.2	3.74
P3 (2000-04)	Maximum Tillering	745.4	1.32	827.82	2.49	813.41	1.31
	Anthesis	1531.82	1.89	1530.28	2.92	1473.56	3.00
	Physiological Maturity	2138.9	3.66	2028.29	4.12	1925.43	3.41
P4 (2005-09)	Maximum Tillering	726.44	3.97	828.19	2.44	805.31	2.33
	Anthesis	1523.15	2.47	1532.18	2.79	1464.45	3.64
	Physiological Maturity	2131.59	4.01	2041.07	3.46	1930.78	3.12
P5 (2010-14)	Maximum Tillering	771.63	-2.12	859.39	-1.28	836.17	-1.44
	Anthesis	1575.82	-0.95	1569.29	0.36	1495.11	1.51
	Physiological Maturity	2185.58	1.44	2074.96	1.77	1962.69	1.44
P6 (2015-19)	Maximum Tillering	806.42	-6.35	878.31	-3.41	854.74	-3.58
	Anthesis	1658.3	-5.88	1641.43	-4.05	1580.4	-3.96
	Physiological Maturity	2320.26	-4.45	2196.92	-3.88	2090.47	-4.76

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.28: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Kapurthala

Kapurthala							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
P1 (1990-94)	Maximum Tillering	728.28	3.70	800.1	6.04	777.74	5.96
	Anthesis	1482.83	5.26	1480.58	6.38	1410.28	7.62
	Physiological Maturity	2068.65	7.18	1958.2	7.84	1845.08	7.91
P2 (1995-99)	Maximum Tillering	724.43	4.25	802.63	5.70	783.37	5.20
	Anthesis	1473.62	5.92	1465.29	7.49	1406.5	7.91
	Physiological Maturity	2063.37	7.45	1959.24	7.78	1853.06	7.44
P3 (2000-04)	Maximum Tillering	720.49	4.82	800.61	5.97	786.87	4.73
	Anthesis	1481.71	5.34	1480.81	6.36	1426.85	6.37
	Physiological Maturity	2071.23	7.04	1964.56	7.49	1865.71	6.72
P4 (2005-09)	Maximum Tillering	730.905	3.33	818.535	3.65	793.805	3.82
	Anthesis	1524.095	2.41	1524.9	3.29	1459.125	4.02
	Physiological Maturity	2129.315	4.12	2029.405	4.06	1917.875	3.81
P5 (2010-14)	Maximum Tillering	821.84	-8.10	889	-4.57	858.84	-4.04
	Anthesis	1683.06	-7.26	1656.91	-4.94	1588.57	-4.46
	Physiological Maturity	2346.13	-5.50	2219.82	-4.87	2106.43	-5.48
P6 (2015-19)	Maximum Tillering	830.45	-9.06	897.43	-5.46	866.17	-4.86
	Anthesis	1697.64	-8.06	1671.13	-5.75	1601.93	-5.25
	Physiological Maturity	2368.56	-6.39	2240.85	-5.76	2125.97	-6.35

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.29: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Jalandhar

Jalandhar							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
P1 (1990-94)	Maximum Tillering	728.9	3.62	800.73	5.95	778.36	5.88
	Anthesis	1483.9	5.18	1481.55	6.31	1411.2	7.55
	Physiological Maturity	2069.87	7.11	1959.33	7.78	1846.15	7.85
P2 (1995-99)	Maximum Tillering	724.62	4.23	802.96	5.66	783.84	5.14
	Anthesis	1474.08	5.88	1465.79	7.45	1407.08	7.87
	Physiological Maturity	2063.98	7.42	1959.84	7.75	1853.74	7.41
P3 (2000-04)	Maximum Tillering	721.02	4.75	801.41	5.86	787.79	4.61
	Anthesis	1483.06	5.24	1482.17	6.26	1428.14	6.27
	Physiological Maturity	2072.89	6.96	1966.17	7.40	1867.27	6.63
P4 (2005-09)	Maximum Tillering	706.78	6.86	796.5	6.52	773.82	6.50
	Anthesis	1475.27	5.80	1481.57	6.31	1416.81	7.12
	Physiological Maturity	2063.06	7.47	1971.86	7.09	1864.9	6.76
P5 (2010-14)	Maximum Tillering	707.8482	6.70	790.5731	7.31	795.1499	3.64
	Anthesis	1480.813	5.40	1480.97	6.35	1417.475	7.07
	Physiological Maturity	2059.374	7.66	1960.963	7.69	1855.05	7.33
P6 (2015-19)	Maximum Tillering	836.22	-9.68	900.71	-5.81	868.43	-5.10
	Anthesis	1699.39	-8.16	1668.91	-5.63	1599.76	-5.13
	Physiological Maturity	2369.23	-6.42	2237.75	-5.63	2125.09	-6.31

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.30: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Ludhiana

Ludhiana							
Pentad	Phenological Stages	Transplanting Window I (13 June)		Transplanting Window II (21 June)		Transplanting Window III (29 June)	
		AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)
P1 (1990-94)	Maximum Tillering	746.2	1.21	823.7	2.99	806.2	2.22
	Anthesis	1532.8	1.83	1532.7	2.76	1463.0	3.74
	Physiological Maturity	2140.5	3.58	2028.2	4.12	1914.3	4.01
P2 (1995-99)	Maximum Tillering	736.1	2.60	818.5	3.65	807.3	2.08
	Anthesis	1516.6	2.91	1511.5	4.20	1454.2	4.37
	Physiological Maturity	2134.4	3.88	2030.1	4.02	1925.1	3.43
P3 (2000-04)	Maximum Tillering	744.7	1.42	835.0	1.61	826.5	-0.29
	Anthesis	1551.5	0.60	1554.3	1.33	1500.0	1.18
	Physiological Maturity	2170.9	2.13	2063.4	2.35	1963.0	1.43
P4 (2005-09)	Maximum Tillering	724.5	4.24	828.9	2.35	811.2	1.59
	Anthesis	1537.3	1.53	1546.3	1.85	1478.3	2.67
	Physiological Maturity	2141.3	3.54	2051.0	2.96	1941.9	2.53
P5 (2010-14)	Maximum Tillering	760.7	-0.72	854.5	-0.72	835.9	-1.41
	Anthesis	1567.9	-0.45	1567.9	0.45	1498.9	1.26
	Physiological Maturity	2178.1	1.79	2072.8	1.88	1962.4	1.46
P6 (2015-19)	Maximum Tillering	748.1	0.96	835.9	1.49	821.7	0.30
	Anthesis	1559.6	0.08	1559.5	0.99	1505.6	0.81
	Physiological Maturity	2194.97	1.01	2085.39	1.26	1979.48	0.58

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.31: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Moga

Moga							
Pentad	Phenological Stages	Transplanting Window I (13 June)		Transplanting Window II (21 June)		Transplanting Window III (29 June)	
		AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)
P1 (1990-94)	Maximum Tillering	766.18	-1.43	842.26	0.73	820.12	0.49
	Anthesis	1560.48	0.02	1555.26	1.27	1481.99	2.41
	Physiological Maturity	2168.74	2.23	2053	2.86	1935.63	2.86
P2 (1995-99)	Maximum Tillering	755.11	0.02	840.56	0.93	821.5	0.32
	Anthesis	1543.71	1.11	1537.24	2.46	1474.63	2.92
	Physiological Maturity	2161.14	2.59	2053.17	2.85	1941.06	2.57
P3 (2000-04)	Maximum Tillering	753.18	0.27	843.44	0.59	832.38	-0.99
	Anthesis	1558.2	0.17	1559.96	0.96	1504.2	0.90
	Physiological Maturity	2178.22	1.78	2069.21	2.06	1966.34	1.25
P4 (2005-09)	Maximum Tillering	753.96	0.17	851.13	-0.32	830.6	-0.78
	Anthesis	1583.86	-1.46	1588.49	-0.85	1525.26	-0.49
	Physiological Maturity	2217.61	-0.02	2114.94	-0.15	2004.32	-0.66
P5 (2010-14)	Maximum Tillering	841.7	-10.27	910.29	-6.80	881.41	-6.50
	Anthesis	1725.13	-9.53	1697.99	-7.24	1629.01	-6.83
	Physiological Maturity	2400.4	-7.64	2268.43	-6.91	2153.53	-7.55
P6 (2015-19)	Maximum Tillering	850.29	-11.18	919.76	-7.76	889.54	-7.36
	Anthesis	1739.63	-10.28	1713.18	-8.07	1642.79	-7.61
	Physiological Maturity	2424.12	-8.54	2291.38	-7.84	2175.82	-8.49

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.32: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Fatehgarh Sahib

Fatehgarh Sahib							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
P1 (1990-94)	Maximum Tillering	687.83	9.80	753.86	12.54	732.91	12.44
	Anthesis	1399.7	11.51	1393.25	13.05	1327.36	14.34
	Physiological Maturity	1946.78	13.89	1841.39	14.68	1736.87	14.63
P2 (1995-99)	Maximum Tillering	677.58	11.46	754.7	12.42	738.35	11.61
	Anthesis	1386.39	12.58	1380.3	14.11	1324.29	14.61
	Physiological Maturity	1941.63	14.19	1844.82	14.47	1745.71	14.05
P3 (2000-04)	Maximum Tillering	672.53	12.30	752.92	12.68	744.91	10.63
	Anthesis	1393.63	12.00	1395.64	12.85	1347.73	12.62
	Physiological Maturity	1951.77	13.59	1854.47	13.87	1765.58	12.77
P4 (2005-09)	Maximum Tillering	693.77	8.86	778.905	8.92	758.5	8.65
	Anthesis	1451.885	7.50	1452.575	8.43	1395.295	8.78
	Physiological Maturity	2035.07	8.94	1939.42	8.89	1840.025	8.21
P5 (2010-14)	Maximum Tillering	824.42	-8.39	885.99	-4.24	893.83	-3.50
	Anthesis	1674.27	-6.78	1645.68	-4.29	1659.3	-3.76
	Physiological Maturity	2344	-5.41	2212.28	-4.54	2233.5	-5.48
P6 (2015-19)	Maximum Tillering	831.24	-9.14	853.97	-5.08	860.47	-4.23
	Anthesis	1686.24	-7.44	1577.12	-5.08046	1590.38	-4.57
	Physiological Maturity	2365.31	-6.27	2106.39	-5.45	2126.35	-6.36

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.33: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Patiala

Patiala							
Pentad	Phenological Stages	Transplanting Window I (13 June)		Transplanting Window II (21 June)		Transplanting Window III (29 June)	
		AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)
P1 (1990-94)	Maximum Tillering	695.8	8.54	762.21	11.31	740.97	11.22
	Anthesis	1415.08	10.30	1408.21	11.84	1341.55	13.13
	Physiological Maturity	1968.08	12.65	1861.65	13.43	1756.13	13.37
P2 (1995-99)	Maximum Tillering	685.85	10.12	763.39	11.14	746.73	10.36
	Anthesis	1402.39	11.30	1396.03	12.82	1339.23	13.33
	Physiological Maturity	1964.2	12.88	1866.19	13.16	1765.92	12.75
P3 (2000-04)	Maximum Tillering	680.51	10.98	761.71	11.38	753.56	9.36
	Anthesis	1409.48	10.74	1411.25	11.60	1362.55	11.39
	Physiological Maturity	1974.08	12.31	1875.74	12.58	1785.75	11.49
P4 (2005-09)	Maximum Tillering	695.3743	8.61	792.5043	7.05	775.1743	6.31
	Anthesis	1465.914	6.47	1474.624	6.81	1414.844	7.27
	Physiological Maturity	2047.684	8.27	1959.124	7.79	1860.544	7.01
P5 (2010-14)	Maximum Tillering	776.12	-2.69	868.76	-2.34	852.42	-3.32
	Anthesis	1590.95	-1.90	1592.97	-1.13	1524.099	-0.42
	Physiological Maturity	2215.776	0.06	2108.127	0.17	1997.087	-0.30
P6 (2015-19)	Maximum Tillering	817.0	-7.56	883.4	-3.96	852.5	-3.33
	Anthesis	1657.6	-5.84	1637.3	-3.81	1571.7	-3.43
	Physiological Maturity	2331.7	-4.91	2202.6	-4.12	2095.3	-4.98

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.34: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Sangrur

Sangrur							
Pentad	Phenological Stages	Transplanting Window I (13 June)		Transplanting Window II (21 June)		Transplanting Window III (29 June)	
		AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)
P1 (1990-94)	Maximum Tillering	759.31	-0.53	833.65	1.77	811.76	1.52
	Anthesis	1545.36	1.00	1539.24	2.32	1466.73	3.48
	Physiological Maturity	2147.56	3.24	2032.51	3.90	1917.12	3.85
P2 (1995-99)	Maximum Tillering	749.09	0.82	833.41	1.80	814.67	1.16
	Anthesis	1530.34	1.99	1523.48	3.38	1461.34	3.86
	Physiological Maturity	2142.38	3.49	2035.37	3.75	1924.69	3.45
P3 (2000-04)	Maximum Tillering	746.72	1.14	835.53	1.54	824.74	-0.08
	Anthesis	1543.35	1.13	1544.4	1.98	1489.04	1.93
	Physiological Maturity	2157.48	2.76	2049.15	3.06	1947.65	2.23
P4 (2005-09)	Maximum Tillering	748.81	0.86	844.59	0.45	824.485	-0.05
	Anthesis	1571.86	-0.70	1575.97	-0.06	1513.375	0.29
	Physiological Maturity	2201.26	0.72	2098.525	0.63	1990.41	0.03
P5 (2010-14)	Maximum Tillering	841.31	-10.23	908.73	-6.64	879.53	-6.30
	Anthesis	1720.04	-9.26	1694.3	-7.04	1624.64	-6.58
	Physiological Maturity	2402.71	-7.73	2269.47	-6.95	2160.39	-7.84
P6 (2015-19)	Maximum Tillering	847.37	-10.87	914.82	-7.26	884.84	-6.86
	Anthesis	1730.09	-9.79	1704.2	-7.58	1634.13	-7.12
	Physiological Maturity	2418.96	-8.34	2285.04	-7.58	2175.19	-8.47

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.35: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Faridkot

Faridkot							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
P1 (1990-94)	Maximum Tillering	776.4	-2.72	852.99	-0.54	829.83	-0.69
	Anthesis	1580.15	-1.22	1574.85	0.01	1499.35	1.23
	Physiological Maturity	2195.17	1.00	2077.67	1.64	1957.94	1.69
P2 (1995-99)	Maximum Tillering	765.91	-1.39	852.55	-0.49	833.62	-1.14
	Anthesis	1566.25	-0.35	1560.62	0.92	1497.84	1.33
	Physiological Maturity	2194.03	1.05	2085.14	1.28	1971.9	0.97
P3 (2000-04)	Maximum Tillering	762.91	-1.00	854.41	-0.70	844.08	-2.37
	Anthesis	1581.13	-1.29	1582.58	-0.48	1525.85	-0.53
	Physiological Maturity	2210.88	0.28	2100.23	0.55	1995.87	-0.24
P4 (2005-09)	Maximum Tillering	763.65	-1.10	861.89	-1.57	840.84	-1.99
	Anthesis	1603.705	-2.68	1608.865	-2.10	1545.12	-1.77
	Physiological Maturity	2254.365	-1.65	2150.945	-1.82	2038.655	-2.34
P5 (2010-14)	Maximum Tillering	848.65	-11.01	919.67	-7.75	892.12	-7.62
	Anthesis	1743.54	-10.48	1716.34	-8.23	1646.41	-7.81
	Physiological Maturity	2421.82	-8.45	2288.72	-7.73	2172.57	-8.36
P6 (2015-19)	Maximum Tillering	854.44	-11.61	926.17	-8.40	898.28	-8.26
	Anthesis	1754.49	-11.04	1727.64	-8.84	1657.57	-8.44
	Physiological Maturity	2439.79	-9.13	2306.31	-8.44	2189.64	-9.07

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.36: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Firozpur

Firozpur							
Pentad	Phenological Stages	Transplanting Window I (13 June)		Transplanting Window II (21 June)		Transplanting Window III (29 June)	
		AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)
P1 (1990-94)	Maximum Tillering	773.9	-2.41	850.15	-0.21	827.1	-0.36
	Anthesis	1574.9	-0.90	1569.85	0.33	1494.77	1.54
	Physiological Maturity	2188.85	1.29	2071.73	1.93	1952.45	1.98
P2 (1995-99)	Maximum Tillering	764.73	-1.24	850.58	-0.26	831.44	-0.88
	Anthesis	1562.3	-0.10	1556.15	1.21	1493.62	1.62
	Physiological Maturity	2188.28	1.32	2079.4	1.56	1966.48	1.25
P3 (2000-04)	Maximum Tillering	761.18	-0.78	851.31	-0.34	840.23	-1.92
	Anthesis	1575.04	-0.90	1575.97	-0.06	1519.13	-0.09
	Physiological Maturity	2201.95	0.69	2091.19	0.98	1986.88	0.21
P4 (2005-09)	Maximum Tillering	763.09	-1.03	861.42	-1.51	840.105	-1.91
	Anthesis	1601.355	-2.53	1605.96	-1.93	1541.76	-1.56
	Physiological Maturity	2247.835	-1.37	2144.53	-1.53	2032.27	-2.03
P5 (2010-14)	Maximum Tillering	846.85	-10.82	919.4	-7.72	892.96	-7.71
	Anthesis	1743.26	-10.47	1716.03	-8.22	1645.74	-7.78
	Physiological Maturity	2415.78	-8.22	2282.97	-7.50	2168.41	-8.18
P6 (2015-19)	Maximum Tillering	853.09	-11.47	925.86	-8.37	899.37	-8.37
	Anthesis	1754.91	-11.06	1727.8	-8.84	1657.66	-8.44
	Physiological Maturity	2434.71	-8.94	2301.09	-8.23	2186.22	-8.93

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.37: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Muktsar

Muktsar							
Pentad	Phenological Stages	Transplanting Window I (13 June)		Transplanting Window II (21 June)		Transplanting Window III (29 June)	
		AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)
P1 (1990-94)	Maximum Tillering	778.29	-2.96	854.71	-0.74	831.57	-0.90
	Anthesis	1583.33	-1.42	1577.68	-0.17	1502.01	1.05
	Physiological Maturity	2199.23	0.81	2081.45	1.46	1961.71	1.49
P2 (1995-99)	Maximum Tillering	768.35	-1.70	854.97	-0.77	835.96	-1.42
	Anthesis	1570.18	-0.60	1564.3	0.68	1501.32	1.09
	Physiological Maturity	2199.38	0.81	2090.19	1.03	1976.85	0.72
P3 (2000-04)	Maximum Tillering	764.74	-1.24	856.15	-0.91	845.67	-2.55
	Anthesis	1584.17	-1.48	1585.3	-0.65	1528.32	-0.69
	Physiological Maturity	2215.17	0.09	2104.22	0.36	1999.65	-0.43
P4 (2005-09)	Maximum Tillering	767.24	-1.56	866.28	-2.06	845.32	-2.51
	Anthesis	1610.685	-3.10	1616.04	-2.54	1552.17	-2.22
	Physiological Maturity	2264.11	-2.08	2160.285	-2.25	2048.055	-2.79
P5 (2010-14)	Maximum Tillering	858.63	-12.04	932.07	-8.98	904.53	-8.89
	Anthesis	1764.08	-11.52	1738.1	-9.38	1667.85	-9.00
	Physiological Maturity	2452.23	-9.59	2318.33	-8.91	2201.14	-9.55
P6 (2015-19)	Maximum Tillering	864.96	-12.68	938.5	-9.60	910.24	-9.46
	Anthesis	1775.14	-12.07	1749.22	-9.96	1678.58	-9.58
	Physiological Maturity	2470.18	-10.25	2335.54	-9.58	2216.89	-10.19

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.38 : Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Bathinda

Bathinda							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
P1 (1990-94)	Maximum Tillering	771.79	-2.14	847.48	0.11	825.01	-0.11
	Anthesis	1570.45	-0.61	1564.51	0.67	1490.23	1.85
	Physiological Maturity	2181.81	1.62	2065.14	2.26	1947.07	2.26
P2 (1995-99)	Maximum Tillering	761.69	-0.85	847.4	0.12	828.4	-0.52
	Anthesis	1556.12	0.30	1549.58	1.64	1486.7	2.09
	Physiological Maturity	2178.88	1.75	2070.27	2.00	1957.68	1.70
P3 (2000-04)	Maximum Tillering	758.89	-0.48	849.34	-0.11	838.51	-1.72
	Anthesis	1569.67	-0.57	1570.68	0.28	1514.21	0.23
	Physiological Maturity	2194.23	1.04	2084.11	1.33	1980.52	0.53
P4 (2005-09)	Maximum Tillering	746.01	1.24	856.12	-0.90	838.42	-1.71
	Anthesis	1579.37	-1.18	1590.36	-0.97	1522.38	-0.30
	Physiological Maturity	2204.62	0.57	2109.87	0.09	2000.28	-0.46
P5 (2010-14)	Maximum Tillering	802.73	-5.91	893.5	-5.05	871.2	-5.41
	Anthesis	1637.68	-4.69	1628.42	-3.28	1549.9	-2.07
	Physiological Maturity	2262.45	-2.00	2149	-1.73	2029.4	-1.89
P6 (2015-19)	Maximum Tillering	750.69	0.61	839.46	1.06	825.21	-0.13
	Anthesis	1567.3	-0.41	1569.06	0.38	1514.35	0.22
	Physiological Maturity	2210.34	0.31	2104.32	0.35	1999.48	-0.42

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.39: Spatio-temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Mansa

Mansa							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
P1 (1990-94)	Maximum Tillering	774.15	-2.44	847.12	0.15	824.8	-0.08
	Anthesis	1571.73	-0.70	1563.23	0.75	1488.43	1.97
	Physiological Maturity	2182.34	1.59	2065.69	2.23	1948.85	2.16
P2 (1995-99)	Maximum Tillering	766.82	-1.51	851.2	-0.33	832.38	-0.99
	Anthesis	1562.37	-0.10	1554.76	1.30	1491.28	1.77
	Physiological Maturity	2187.98	1.33	2079.17	1.57	1967.21	1.21
P3 (2000-04)	Maximum Tillering	762.51	-0.95	852.96	-0.53	841.94	-2.12
	Anthesis	1573.28	-0.79	1573.38	0.10	1515.49	0.15
	Physiological Maturity	2198.68	0.84	2088.52	1.11	1984.54	0.33
P4 (2005-09)	Maximum Tillering	762.47	-0.95	860.55	-1.41	841.41	-2.06
	Anthesis	1599.45	-2.42	1603.59	-1.78	1540.77	-1.49
	Physiological Maturity	2240.43	-1.04	2135.22	-1.10	2026.49	-1.75
P5 (2010-14)	Maximum Tillering	853.13	-11.47	924.31	-8.21	895.82	-8.01
	Anthesis	1745.3	-10.57	1719.88	-8.42	1649.1	-7.96
	Physiological Maturity	2434.69	-8.94	2300.25	-8.19	2189.15	-9.05
P6 (2015-19)	Maximum Tillering	858.6	-12.0	930.32	-8.81	900.57	-8.49
	Anthesis	1754.6	-11.0	1729.70	-8.94	1658.04	-8.46
	Physiological Maturity	2450.1	-9.5	2315.69	-8.81	2203.37	-9.64

(Percent deviation of thermal requirement is from actual sown crop)

4.5 PREDICTED TEMPORAL VARIABILITY IN THERMAL REQUIREMENTS OF RICE AS AFFECTED BY TRANSPLANTING WINDOWS

Predicted Pentad variability in thermal requirements of rice was analyzed for three crop stages i.e. maximum tillering, anthesis and physiological maturity. The data was compared with actual accumulated heat units by computation of percentage deviation of AGDD from actual sown crop heat units. The result obtained are presented in the Tables 4.40 to 4.56.

a) Under transplanting window I, the maximum positive deviation (%) in AGDD at maximum tillering (20.9), anthesis (19.9) and physiological maturity (18) is likely to occur during the period F6 (2045-2049) at Muktsar. The lowest deviation (%) of AGDD at maximum tillering (9.6), anthesis (7.2) and physiological maturity (5.4)was observed at Hoshiarpur during F1 (2020-2024) period.

b) Under transplanting window II, the maximum positive deviation (%) in AGDD at maximum tillering (16.9), anthesis (17.2) and physiological maturity (17.2) is likely to occur during the period F6 (2045-2049) at Muktsar. The lowest deviation (%) of AGDD at maximum tillering (4.5) was observed at Hoshiarpur, for anthesis (2.4) at Gurdaspur and for physiological maturity (4.4) at Hoshiarpur for F1 (2020-2024) period.

c) Under transplanting window III, the maximum positive deviation (%) in AGDD at maximum tillering (16.7), anthesis (16.8) and physiological maturity (18) is likely to occur during the period F6 (2045-2049) at Muktsar. The lowest deviation (%) of AGDD at maximum tillering (3.4), anthesis (3.6)and for physiological maturity (5.3) during F1 (2020-2024) for Hoshiarpur.

Table 4.40: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Gurdaspur

Gurdaspur							
Pentad	Phenological Stages	Transplanting Window I (13 June)		Transplanting Window II (21 June)		Transplanting Window III (29 June)	
		AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)
F1 (2020-24)	Maximum Tillering	838.6	11.0	898.0	5.8	864.1	4.8
	Anthesis	1688.3	8.2	1612.5	2.4	1582.6	4.3
	Physiological Maturity	2354.4	6.2	2219.1	5.1	2112.7	6.1
F2 (2025-29)	Maximum Tillering	846.1	12.0	906.4	6.8	872.2	5.8
	Anthesis	1703.1	9.1	1626.9	3.3	1596.6	5.2
	Physiological Maturity	2375.4	7.1	2239.2	6.0	2131.0	7.0
F3 (2030-34)	Maximum Tillering	853.1	13.0	913.5	7.7	878.3	6.6
	Anthesis	1717.4	10.0	1640.9	4.2	1610.0	6.1
	Physiological Maturity	2396.9	8.1	2259.6	7.0	2149.5	8.0
F4 (2035-39)	Maximum Tillering	859.7	13.8	919.4	8.4	883.9	7.3
	Anthesis	1729.3	10.8	1652.5	4.9	1622.3	6.9
	Physiological Maturity	2417.3	9.0	2278.7	7.9	2168.2	8.9
F5 (2040-44)	Maximum Tillering	868.8	15.0	928.3	9.4	892.9	8.3
	Anthesis	1744.7	11.8	1667.1	5.8	1637.3	7.9
	Physiological Maturity	2442.3	10.2	2302.3	9.0	2190.7	10.0
F6 (2045-49)	Maximum Tillering	877.5	16.2	937.8	10.5	902.3	9.5
	Anthesis	1762.3	12.9	1684.3	6.9	1654.3	9.0
	Physiological Maturity	2467.5	11.3	2326.6	10.2	2213.8	11.2

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.41: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Hoshiarpur

Hoshiarpur							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
F1 (2020-24)	Maximum Tillering	827.6	9.6	779.7	4.5	852.4	3.4
	Anthesis	1672.7	7.2	1620.8	2.9	1572.4	3.6
	Physiological Maturity	2336.0	5.4	2205.7	4.4	2095.8	5.3
F2 (2025-29)	Maximum Tillering	832.5	10.2	785.2	5.2	857.1	4.0
	Anthesis	1682.4	7.8	1632.2	3.6	1582.9	4.3
	Physiological Maturity	2352.8	6.1	2223.1	5.3	2111.4	6.0
F3 (2030-34)	Maximum Tillering	843.1	11.6	791.6	6.0	864.8	4.9
	Anthesis	1696.2	8.7	1641.7	4.2	1593.7	5.0
	Physiological Maturity	2374.3	7.1	2240.0	6.1	2128.9	6.9
F4 (2035-39)	Maximum Tillering	847.7	12.2	797.0	6.7	871.9	5.8
	Anthesis	1709.1	9.5	1655.0	5.1	1608.1	6.0
	Physiological Maturity	2396.1	8.1	2260.2	7.0	2151.1	8.0
F5 (2040-44)	Maximum Tillering	854.9	13.2	804.4	7.7	881.3	6.9
	Anthesis	1726.4	10.6	1671.9	6.2	1626.2	7.1
	Physiological Maturity	2423.1	9.3	2284.5	8.2	2177.2	9.3
F6 (2045-49)	Maximum Tillering	865.2	14.6	815.1	9.1	892.6	8.3
	Anthesis	1747.3	11.9	1693.4	7.5	1646.3	8.5
	Physiological Maturity	2452.9	10.6	2314.3	9.6	2204.5	10.7

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.42: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at S.B.S Nagar

S.B.S Nagar							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
F1 (2020-24)	Maximum Tillering	847.4	12.2	913.5	7.7	882.3	7.1
	Anthesis	1722.8	10.4	1696.4	7.7	1626.7	7.2
	Physiological Maturity	2411.1	8.8	2277.6	7.9	2169.5	9.0
F2 (2025-29)	Maximum Tillering	850.0	12.5	915.0	7.9	882.8	7.1
	Anthesis	1721.2	10.3	1694.3	7.6	1624.4	7.0
	Physiological Maturity	2410.4	8.7	2276.7	7.8	2168.8	8.9
F3 (2030-34)	Maximum Tillering	852.6	12.9	916.6	8.0	884.3	7.3
	Anthesis	1727.3	10.7	1700.8	8.0	1631.7	7.5
	Physiological Maturity	2424.7	9.4	2290.0	8.4	2181.9	9.6
F4 (2035-39)	Maximum Tillering	861.4	14.1	926.6	9.2	894.1	8.5
	Anthesis	1745.1	11.8	1718.7	9.1	1648.8	8.6
	Physiological Maturity	2449.9	10.5	2314.1	9.6	2204.1	10.7
F5 (2040-44)	Maximum Tillering	870.8	15.3	936.9	10.4	904.2	9.7
	Anthesis	1763.8	13.0	1737.5	10.3	1666.8	9.8
	Physiological Maturity	2476.8	11.7	2339.9	10.8	2228.6	11.9
F6 (2045-49)	Maximum Tillering	884.1	17.1	947.0	11.6	914.0	10.9
	Anthesis	1786.1	14.4	1756.6	11.5	1685.1	11.0
	Physiological Maturity	2507.9	13.1	2366.6	12.1	2253.9	13.2

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.43: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Rupnagar

Rupnagar							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
F1 (2020-24)	Maximum Tillering	833.8	10.4	891.0	5.0	855.3	3.8
	Anthesis	1686.1	8.0	1658.2	5.3	1589.2	4.7
	Physiological Maturity	2368.9	6.8	2234.7	5.8	2127.3	6.8
F2 (2025-29)	Maximum Tillering	839.5	11.2	897.8	5.8	862.7	4.7
	Anthesis	1698.6	8.8	1670.9	6.1	1601.5	5.5
	Physiological Maturity	2387.7	7.7	2253.6	6.7	2144.8	7.7
F3 (2030-34)	Maximum Tillering	847.8	12.3	907.3	6.9	872.0	5.8
	Anthesis	1713.0	9.8	1685.2	7.0	1615.0	6.4
	Physiological Maturity	2408.6	8.6	2273.6	7.7	2163.7	8.7
F4 (2035-39)	Maximum Tillering	854.8	13.2	914.1	7.7	877.3	6.5
	Anthesis	1725.4	10.5	1699.0	7.9	1627.8	7.2
	Physiological Maturity	2429.9	9.6	2294.4	8.6	2181.8	9.6
F5 (2040-44)	Maximum Tillering	861.4	14.1	918.9	8.3	883.1	7.2
	Anthesis	1739.3	11.4	1709.6	8.5	1641.6	8.2
	Physiological Maturity	2451.9	10.6	2309.9	9.4	2201.1	10.6
F6 (2045-49)	Maximum Tillering	871.9	15.4	932.8	9.9	894.5	8.5
	Anthesis	1760.7	12.8	1735.3	10.2	1662.4	9.5
	Physiological Maturity	2483.0	12.0	2345.6	11.1	2229.5	12.0

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.44: Predicted temporal variability in thermal requirement of rice as affected by transplanting window and phenology at Amritsar

Amritsar							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
F1 (2020-24)	Maximum Tillering	835.26	10.6	906.48	6.8	879.42	6.7
	Anthesis	1718.13	10.1	1695.31	7.6	1629.22	7.3
	Physiological Maturity	2399.32	8.2	2271.62	7.6	2155.27	8.2
F2 (2025-29)	Maximum Tillering	841.01	11.4	912.68	7.6	885.9	7.5
	Anthesis	1729.97	10.8	1706.59	8.4	1640.46	8.1
	Physiological Maturity	2416.29	9.0	2287.51	8.3	2173.97	9.2
F3 (2030-34)	Maximum Tillering	849.65	12.5	922.47	8.7	895.03	8.6
	Anthesis	1746.88	11.9	1724.07	9.5	1656.79	9.2
	Physiological Maturity	2440.88	10.1	2311.33	9.5	2196.06	10.3
F4 (2035-39)	Maximum Tillering	855.92	13.3	929.11	9.5	901.97	9.4
	Anthesis	1761.61	12.9	1738.72	10.4	1670.73	10.1
	Physiological Maturity	2463.43	11.1	2332.85	10.5	2216.38	11.3
F5 (2040-44)	Maximum Tillering	863.71	14.4	935.84	10.3	911.08	10.6
	Anthesis	1779.92	14.0	1756.11	11.5	1687.48	11.2
	Physiological Maturity	2491.28	12.4	2358.82	11.7	2240.97	12.6
F6 (2045-49)	Maximum Tillering	792.66	16.1	881.07	11.8	870.75	12.1
	Anthesis	1706.64	15.3	1715.83	12.8	1670.79	12.6
	Physiological Maturity	2458	13.7	2353.64	13.1	2254.25	14.0

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.45: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Kapurthala

Kapurthala							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
F1 (2020-24)	Maximum Tillering	840.5	11.3	907.7	7.0	875.1	6.2
	Anthesis	1717.7	10.1	1691.6	7.4	1621.2	6.8
	Physiological Maturity	2400.0	8.2	2270.5	7.5	2153.7	8.2
F2 (2025-29)	Maximum Tillering	847.0	12.2	914.8	7.8	882.5	7.1
	Anthesis	1731.1	10.9	1704.3	8.2	1633.8	7.6
	Physiological Maturity	2419.3	9.1	2288.4	8.4	2171.6	9.1
F3 (2030-34)	Maximum Tillering	852.9	12.9	920.4	8.5	889.5	7.9
	Anthesis	1744.1	11.7	1714.9	8.9	1645.6	8.4
	Physiological Maturity	2438.1	10.0	2304.7	9.1	2190.1	10.0
F4 (2035-39)	Maximum Tillering	856.9	13.5	923.0	8.8	891.1	8.1
	Anthesis	1754.7	12.4	1726.5	9.6	1656.5	9.1
	Physiological Maturity	2457.6	10.8	2323.1	10.0	2206.9	10.8
F5 (2040-44)	Maximum Tillering	866.1	14.7	933.3	10.0	901.1	9.3
	Anthesis	1772.5	13.6	1744.3	10.8	1673.6	10.3
	Physiological Maturity	2483.4	12.0	2347.8	11.2	2230.4	12.0
F6 (2045-49)	Maximum Tillering	877.3	16.2	943.6	11.2	908.5	10.2
	Anthesis	1789.8	14.7	1760.8	11.8	1688.8	11.3
	Physiological Maturity	2510.8	13.2	2373.9	12.4	2254.6	13.2

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.46: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Jalandhar

Jalandhar							
Pentad	Phenological Stages	Transplanting Window I (13 June)		Transplanting Window II (21 June)		Transplanting Window III (29 June)	
		AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)
F1 (2020-24)	Maximum Tillering	846.8	12.1	911.8	7.5	879.2	6.7
	Anthesis	1718.9	10.1	1688.1	7.2	1618.7	6.7
	Physiological Maturity	2399.2	8.2	2266.3	7.3	2152.8	8.1
F2 (2025-29)	Maximum Tillering	853.8	13.0	919.5	8.4	886.8	7.6
	Anthesis	1732.7	11.0	1702.0	8.1	1632.0	7.5
	Physiological Maturity	2419.2	9.1	2285.4	8.2	2171.0	9.0
F3 (2030-34)	Maximum Tillering	861.4	14.1	928.0	9.4	894.9	8.6
	Anthesis	1747.7	12.0	1717.0	9.0	1646.3	8.5
	Physiological Maturity	2440.9	10.1	2292.9	8.6	2190.6	10.0
F4 (2035-39)	Maximum Tillering	868.2	15.0	934.0	10.1	900.1	9.2
	Anthesis	1761.2	12.8	1731.0	9.9	1659.5	9.3
	Physiological Maturity	2462.6	11.1	2326.7	10.2	2209.7	11.0
F5 (2040-44)	Maximum Tillering	876.6	16.1	942.1	11.0	907.2	10.1
	Anthesis	1777.4	13.9	1747.3	10.9	1675.0	10.4
	Physiological Maturity	2487.7	12.2	2350.6	11.3	2232.0	12.1
F6 (2045-49)	Maximum Tillering	887.6	17.5	945.1	11.4	916.0	11.2
	Anthesis	1797.0	15.1	1759.9	11.7	1692.9	11.5
	Physiological Maturity	2517.3	13.5	2378.8	12.6	2258.3	13.4

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.47: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Ludhiana

Ludhiana							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
F1 (2020-24)	Maximum Tillering	846.9	12.1	911.0	7.4	886.6	7.6
	Anthesis	1736.5	11.3	1709.3	8.5	1642.2	8.2
	Physiological Maturity	2430.3	9.6	2294.3	8.6	2186.7	9.8
F2 (2025-29)	Maximum Tillering	853.6	13.0	918.6	8.3	894.1	8.5
	Anthesis	1750.3	12.1	1723.2	9.4	1655.7	9.1
	Physiological Maturity	2449.9	10.5	2313.1	9.5	2205.2	10.8
F3 (2030-34)	Maximum Tillering	861.0	14.0	927.1	9.3	902.4	9.5
	Anthesis	1765.8	13.1	1738.7	10.4	1670.6	10.1
	Physiological Maturity	2472.0	11.5	2334.3	10.5	2225.3	11.8
F4 (2035-39)	Maximum Tillering	868.4	15.0	936.2	10.3	911.8	10.6
	Anthesis	1782.1	14.2	1755.3	11.4	1687.1	11.2
	Physiological Maturity	2495.8	12.6	2357.0	11.6	2247.4	12.9
F5 (2040-44)	Maximum Tillering	875.2	15.9	945.4	11.4	922.5	11.9
	Anthesis	1797.8	15.2	1772.6	12.5	1705.5	12.4
	Physiological Maturity	2520.3	13.7	2381.1	12.8	2271.9	14.1
F6 (2045-49)	Maximum Tillering	884.7	17.1	953.3	12.4	930.6	12.9
	Anthesis	1814.5	16.3	1788.8	13.6	1722.1	13.5
	Physiological Maturity	2545.0	14.8	2404.3	13.9	2295.5	15.3

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.48: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Moga

Moga							
Pentad	Phenological Stages	Transplanting Window I (13 June)		Transplanting Window II (21 June)		Transplanting Window III (29 June)	
		AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)
F1 (2020-24)	Maximum Tillering	858.5	13.7	927.2	9.3	896.6	8.8
	Anthesis	1754.5	12.4	1726.8	9.6	1656.5	9.1
	Physiological Maturity	2446.1	10.3	2311.8	9.5	2194.8	10.2
F2 (2025-29)	Maximum Tillering	864.9	14.5	934.4	10.1	903.6	9.7
	Anthesis	1767.3	13.2	1739.8	10.5	1669.0	10.0
	Physiological Maturity	2464.9	11.2	2330.0	10.3	2213.0	11.1
F3 (2030-34)	Maximum Tillering	872.7	15.5	943.1	11.2	912.1	10.7
	Anthesis	1782.9	14.2	1755.5	11.5	1684.1	11.0
	Physiological Maturity	2487.7	12.2	2351.8	11.4	2232.9	12.1
F4 (2035-39)	Maximum Tillering	880.9	16.6	952.0	12.2	920.7	11.7
	Anthesis	1799.2	15.3	1771.9	12.5	1699.8	12.0
	Physiological Maturity	2511.6	13.3	2374.8	12.5	2254.7	13.2
F5 (2040-44)	Maximum Tillering	889.5	17.8	961.4	13.3	929.8	12.8
	Anthesis	1816.4	16.4	1789.2	13.6	1716.5	13.1
	Physiological Maturity	2537.2	14.4	2399.2	13.6	2278.1	14.4
F6 (2045-49)	Maximum Tillering	898.9	19.0	971.6	14.5	939.5	14.0
	Anthesis	1834.9	17.6	1807.8	14.8	1734.5	14.3
	Physiological Maturity	2564.9	15.7	2425.7	14.9	2303.3	15.7

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.49: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Fatehgarh Sahib

Fatehgarh Sahib							
Pentad	Phenological Stages	Transplanting Window I (13 June)		Transplanting Window II (21 June)		Transplanting Window III (29 June)	
		AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)
F1 (2020-24)	Maximum Tillering	840.7	11.3	902.0	6.3	865.9	5.1
	Anthesis	1699.2	8.9	1673.4	6.2	1603.7	5.7
	Physiological Maturity	2390.6	7.8	2257.9	6.9	2148.0	7.9
F2 (2025-29)	Maximum Tillering	843.1	11.6	902.6	6.4	865.4	5.0
	Anthesis	1705.1	9.2	1681.0	6.7	1611.2	6.2
	Physiological Maturity	2404.3	8.4	2271.2	7.5	2159.5	8.5
F3 (2030-34)	Maximum Tillering	849.8	12.5	908.0	7.0	870.1	5.6
	Anthesis	1718.1	10.1	1693.8	7.5	1623.8	7.0
	Physiological Maturity	2425.1	9.4	2290.9	8.5	2178.3	9.4
F4 (2035-39)	Maximum Tillering	859.0	13.7	917.2	8.1	878.7	6.6
	Anthesis	1735.4	11.2	1710.8	8.6	1640.0	8.1
	Physiological Maturity	2450.3	10.5	2314.9	9.6	2201.0	10.5
F5 (2040-44)	Maximum Tillering	868.3	15.0	927.8	9.4	889.1	7.9
	Anthesis	1754.3	12.4	1729.8	9.8	1658.2	9.3
	Physiological Maturity	2477.1	11.7	2340.7	10.8	2225.5	11.8
F6 (2045-49)	Maximum Tillering	878.2	16.3	938.9	10.7	900.1	9.2
	Anthesis	1774.3	13.7	1749.9	11.1	1677.5	10.5
	Physiological Maturity	2505.9	13.0	2368.4	12.2	2251.9	13.1

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.50: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Patiala

Patiala							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
F1 (2020-24)	Maximum Tillering	842.9	11.6	904.2	6.6	866.3	5.1
	Anthesis	1698.3	8.8	1672.6	6.2	1601.6	5.5
	Physiological Maturity	2388.0	7.7	2255.7	6.8	2143.6	7.7
F2 (2025-29)	Maximum Tillering	845.9	12.0	906.8	6.9	868.7	5.4
	Anthesis	1702.8	9.1	1674.8	6.3	1602.6	5.6
	Physiological Maturity	2388.2	7.7	2255.4	6.8	2141.8	7.6
F3 (2030-34)	Maximum Tillering	857.0	13.5	917.8	8.2	878.8	6.6
	Anthesis	1725.0	10.5	1698.8	7.9	1626.6	7.2
	Physiological Maturity	2427.6	9.5	2293.3	8.6	2179.2	9.5
F4 (2035-39)	Maximum Tillering	866.1	14.7	927.6	9.3	888.3	7.8
	Anthesis	1743.4	11.7	1717.2	9.0	1644.3	8.3
	Physiological Maturity	2454.3	10.7	2318.9	9.8	2203.5	10.7
F5 (2040-44)	Maximum Tillering	874.6	15.8	937.0	10.4	897.7	8.9
	Anthesis	1761.2	12.8	1735.1	10.2	1661.6	9.5
	Physiological Maturity	2480.1	11.9	2343.6	11.0	2227.2	11.9
F6 (2045-49)	Maximum Tillering	883.7	17.0	947.2	11.6	907.7	10.1
	Anthesis	1780.2	14.1	1754.4	11.4	1680.2	10.7
	Physiological Maturity	2507.8	13.1	2370.3	12.2	2252.7	13.1

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.51: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Sangrur

Sangrur							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
F1 (2020-24)	Maximum Tillering	854.8	13.2	922.4	8.7	891.6	8.2
	Anthesis	1743.0	11.7	1717.0	9.0	1646.5	8.5
	Physiological Maturity	2439.9	10.0	2305.2	9.2	2194.4	10.2
F2 (2025-29)	Maximum Tillering	860.7	14.0	929.1	9.5	898.3	9.0
	Anthesis	1755.5	12.5	1729.6	9.8	1658.6	9.3
	Physiological Maturity	2458.0	10.9	2322.6	10.0	2211.1	11.1
F3 (2030-34)	Maximum Tillering	866.3	14.7	935.1	10.2	903.7	9.7
	Anthesis	1768.0	13.3	1742.5	10.6	1670.9	10.1
	Physiological Maturity	2477.8	11.8	2341.6	10.9	2228.7	11.9
F4 (2035-39)	Maximum Tillering	871.9	15.5	939.5	10.7	906.1	10.0
	Anthesis	1777.8	13.9	1753.9	11.4	1681.3	10.8
	Physiological Maturity	2496.5	12.6	2360.0	11.8	2244.2	12.7
F5 (2040-44)	Maximum Tillering	880.3	16.6	948.5	11.8	914.8	11.0
	Anthesis	1794.3	15.0	1770.5	12.4	1697.2	11.8
	Physiological Maturity	2520.9	13.7	2383.3	12.9	2266.4	13.8
F6 (2045-49)	Maximum Tillering	890.5	17.9	958.0	12.9	922.3	11.9
	Anthesis	1811.8	16.1	1787.6	13.5	1713.5	12.9
	Physiological Maturity	2548.4	14.9	2409.5	14.1	2291.0	15.1

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.52: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Faridkot

Faridkot							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
F1 (2020-24)	Maximum Tillering	865.52	14.6	939.17	10.7	911.78	10.6
	Anthesis	1778.56	14.0	1753.47	11.3	1682.92	10.9
	Physiological Maturity	2479.16	11.8	2344.07	11.0	2232.63	12.1
F2 (2025-29)	Maximum Tillering	863.35	14.3	937.44	10.5	911.33	10.6
	Anthesis	1777.16	13.9	1753.77	11.4	1683.06	10.9
	Physiological Maturity	2479.68	11.8	2343.59	11.0	2230.97	12.1
F3 (2030-34)	Maximum Tillering	870.75	15.3	945.67	11.5	919.39	11.6
	Anthesis	1792.09	14.8	1768.89	12.3	1697.73	11.9
	Physiological Maturity	2501.75	12.8	2364.85	12.0	2251.32	13.1
F4 (2035-39)	Maximum Tillering	878.88	16.4	954.6	12.5	928.05	12.6
	Anthesis	1808.47	15.9	1785.4	13.4	1713.66	12.9
	Physiological Maturity	2525.95	13.9	2388.09	13.1	2273.48	14.2
F5 (2040-44)	Maximum Tillering	887.69	17.5	964.2	13.6	937.35	13.7
	Anthesis	1826.07	17.0	1803.14	14.5	1730.81	14.0
	Physiological Maturity	2552.13	15.1	2413.2	14.3	2297.45	15.4
F6 (2045-49)	Maximum Tillering	897.13	18.8	974.24	14.8	946.98	14.9
	Anthesis	1844.72	18.2	1821.93	15.7	1748.97	15.2
	Physiological Maturity	2580.01	16.4	2439.9	15.5	2322.92	16.7

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.53: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Firozpur

Firozpur							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
F1 (2020-24)	Maximum Tillering	861.4	14.1	934.8	10.2	908.5	10.2
	Anthesis	1771.1	13.5	1744.0	10.7	1674.1	10.3
	Physiological Maturity	2460.1	11.0	2325.5	10.1	2210.4	11.0
F2 (2025-29)	Maximum Tillering	868.4	15.0	942.6	11.1	916.2	11.2
	Anthesis	1785.2	14.4	1758.2	11.6	1687.9	11.2
	Physiological Maturity	2481.0	11.9	2345.6	11.1	2228.5	11.9
F3 (2030-34)	Maximum Tillering	877.6	16.2	952.3	12.3	924.6	12.2
	Anthesis	1802.2	15.5	1774.6	12.7	1702.9	12.2
	Physiological Maturity	2505.2	13.0	2367.9	12.1	2249.0	13.0
F4 (2035-39)	Maximum Tillering	801.0	6.1	892.3	5.2	878.9	6.7
	Anthesis	1723.8	10.4	1728.2	9.7	1678.7	10.6
	Physiological Maturity	2465.5	11.2	2357.5	11.6	2257.7	13.4
F5 (2040-44)	Maximum Tillering	894.8	18.5	971.9	14.6	942.8	14.4
	Anthesis	1836.6	17.7	1810.4	14.9	1736.3	14.4
	Physiological Maturity	2556.2	15.3	2418.1	14.5	2295.6	15.3
F6 (2045-49)	Maximum Tillering	904.4	19.8	981.9	15.7	952.7	15.6
	Anthesis	1855.6	18.9	1829.2	16.1	1754.7	15.6
	Physiological Maturity	2584.6	16.6	2445.0	15.8	2321.6	16.6

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.54: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Muktsar

Muktsar							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
F1 (2020-24)	Maximum Tillering	872.9	15.6	946.9	11.6	918.1	11.4
	Anthesis	1789.8	14.7	1764.0	12.0	1692.9	11.5
	Physiological Maturity	2493.4	12.5	2358.0	11.7	2238.5	12.4
F2 (2025-29)	Maximum Tillering	879.7	16.5	954.6	12.5	925.7	12.3
	Anthesis	1803.7	15.6	1778.1	12.9	1706.6	12.4
	Physiological Maturity	2513.9	13.4	2377.8	12.6	2257.4	13.4
F3 (2030-34)	Maximum Tillering	887.1	17.5	962.9	13.5	933.8	13.3
	Anthesis	1818.9	16.5	1793.4	13.9	1721.4	13.4
	Physiological Maturity	2536.4	14.4	2399.4	13.6	2278.1	14.4
F4 (2035-39)	Maximum Tillering	895.2	18.5	971.9	14.6	942.5	14.4
	Anthesis	1835.2	17.6	1809.9	14.9	1737.3	14.5
	Physiological Maturity	2560.8	15.5	2422.8	14.7	2300.5	15.5
F5 (2040-44)	Maximum Tillering	904.0	19.7	981.4	15.7	951.8	15.5
	Anthesis	1852.9	18.7	1827.8	16.1	1754.6	15.6
	Physiological Maturity	2587.2	16.7	2448.2	15.9	2324.7	16.8
F6 (2045-49)	Maximum Tillering	913.4	20.9	991.5	16.9	961.5	16.7
	Anthesis	1871.5	19.9	1846.7	17.2	1772.8	16.8
	Physiological Maturity	2615.2	18.0	2475.0	17.2	2350.4	18.0

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.55: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Bathinda

Bathinda							
Pentad	**Phenological Stages**	**Transplanting Window I (13 June)**		**Transplanting Window II (21 June)**		**Transplanting Window III (29 June)**	
		AGDD (ºC day)	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**	**AGDD (ºC day)**	**Deviation (%)**
F1 (2020-24)	Maximum Tillering	868.9	15.0	942.2	11.1	913.2	10.8
	Anthesis	1779.5	14.0	1753.0	11.3	1682.6	10.9
	Physiological Maturity	2482.0	11.9	2348.0	11.2	2230.4	12.0
F2 (2025-29)	Maximum Tillering	874.5	15.8	948.6	11.8	919.7	11.6
	Anthesis	1791.9	14.8	1766.1	12.1	1695.1	11.7
	Physiological Maturity	2501.1	12.8	2365.9	12.0	2248.4	12.9
F3 (2030-34)	Maximum Tillering	879.0	16.4	952.8	12.3	924.5	12.2
	Anthesis	1802.8	15.5	1779.1	13.0	1707.2	12.5
	Physiological Maturity	2520.4	13.7	2382.4	12.8	2267.5	13.9
F4 (2035-39)	Maximum Tillering	886.9	17.4	961.5	13.3	933.1	13.2
	Anthesis	1818.8	16.5	1795.3	14.0	1722.9	13.5
	Physiological Maturity	2544.1	14.8	2405.2	13.9	2289.4	15.0
F5 (2040-44)	Maximum Tillering	895.5	18.6	970.8	14.4	942.1	14.3
	Anthesis	1836.0	17.6	1812.6	15.1	1739.6	14.6
	Physiological Maturity	2569.8	15.9	2429.8	15.1	2312.9	16.2
F6 (2045-49)	Maximum Tillering	904.8	19.8	980.9	15.6	951.7	15.5
	Anthesis	1854.4	18.8	1831.2	16.3	1757.6	15.8
	Physiological Maturity	2597.4	17.2	2456.3	16.3	2338.2	17.4

(Percent deviation of thermal requirement is from actual sown crop)

Table 4.56: Predicted temporal variability in thermal requirement of rice as affected by transplanting windows and phenology at Mansa

Mansa							
Pentad	Phenological Stages	Transplanting Window I (13 June)		Transplanting Window II (21 June)		Transplanting Window III (29 June)	
		AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)	AGDD (ºC day)	Deviation (%)
F1 (2020-24)	Maximum Tillering	865.3	14.6	936.7	10.4	906.9	10.0
	Anthesis	1766.6	13.2	1741.1	10.5	1669.7	10.0
	Physiological Maturity	2469.8	11.4	2334.1	10.5	2222.2	11.6
F2 (2025-29)	Maximum Tillering	871.6	15.4	943.8	11.2	914.0	10.9
	Anthesis	1779.6	14.0	1754.3	11.4	1682.5	10.9
	Physiological Maturity	2488.8	12.3	2352.5	11.4	2239.3	12.5
F3 (2030-34)	Maximum Tillering	878.6	16.3	951.7	12.2	921.9	11.9
	Anthesis	1794.1	14.9	1768.9	12.3	1696.7	11.8
	Physiological Maturity	2510.0	13.2	2373.0	12.4	2254.5	13.2
F4 (2035-39)	Maximum Tillering	886.3	17.4	960.3	13.2	930.2	12.9
	Anthesis	1809.7*	15.9	1784.8	13.3	1712.0	12.8
	Physiological Maturity	2533.2	14.3	2395.3	13.4	2280.3	14.5
F5 (2040-44)	Maximum Tillering	894.9	18.5	969.6	14.3	939.3	14.0
	Anthesis	1826.9	17.1	1802.1	14.4	1728.6	13.9
	Physiological Maturity	2558.7	15.4	2419.7	14.6	2303.6	15.7
F6 (2045-49)	Maximum Tillering	904.2	19.7	979.6	15.5	948.8	15.1
	Anthesis	1845.2	18.2	1820.5	15.6	1746.4	15.1
	Physiological Maturity	2586.1	16.6	2446.0	15.8	2328.6	17.0

(Percent deviation of thermal requirement is from actual sown crop)

CHAPTER-V

SUMMARY

Weather and climate majorly affect the agricultural productivity in any region. The main determinant of agricultural production is climate and is regulated by prevailing climatic factors including light intensity, sunshine duration, rainfall, temperature, air pressure, and humidity level across the region. On global scale both, climate change and agriculture are interrelated processes. In order to study the crop responses to ambient air temperature cardinal temperatures are considered. Environmental conditions when cool led to delay in achieving the maturity stage while high temperature tend the crop towards earlier completion of development stages. So a crop that is sown at same time in large region is not ready to harvest at the expected time. Under Punjab conditions, increase in temperature of 1^0C will decrease the rice yield by 3% (Hundal and Kaur 2007). This alarming situation demand for, analyses of the spatio-temporal variability in climatic patterns at regional scale in order to adopt mitigation strategies on regional basis. Plants require definite temperature for attainment of certain phenological stages. Thermo and photo period is influenced by shifting of the transplanting dates. So study of above effects may help in the deciding the right time of transplanting to achieve higher yield. The estimation of occurrence of various phenological events during the crop growth period in relation to temperature can be done by computing accumulated growing degree days. Heat units in terms of dry matter is known as Heat use efficiency (HUE) which depends on genetic factors, crop type and sowing time. There is good interaction of rice with the existing environment. Under changing climatic scenario for getting full potential performance of rice under given agroclimatic conditions the choice of correct variety and right time of transplanting play a deciding role. The present study entitled **"**Delineation of thermal requirements of rice (*Oryza sativa* L.) staggered in different transplanting windows and their validation**"** was undertaken to accomplish the following objectives:

a) To study the spatio-temporal variations of thermal requirements of rice in Punjab.

b) To validate the thermal requirement with actual experimental data under staggered planting.

c) To study the impact of climate change on future thermal requirements of rice.

The Present investigation was conducted at Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana. Data on rice productivity was collected from statistical abstracts of Punjab (1990-2018). Climatic data from past (1990-2019) and future data (2020-2049) on maximum temperature, minimum temperature during the rice growing period was collected from the Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University (PAU) Ludhiana, India

Meteorological Department, Chandigarh and MarksimGCM software.

Spatio-temporal variability of thermal requirements of rice during different time has been assessed by using spatial interpolation techniques in built in software Arc GIS 10.2.

The salient findings of the study has been summarized as follows:

- Under the three transplanting windows the crop transplanted on 13th June (D_1) took more number of days to reach maturity stage as compared to 21st June (D_2) and 29th June (D_3). The early transplanted crop took more number of days to each phenological stage as compared to delay transplanting. In all the varieties the highest growing degree days (GDD) were accumulated under first date of transplanting i.e. 13th June by variety PR118 (2485) at maturity stage. Transplanting dates and Varieties had significant effect on grain yield. Among the dates of transplanting, D_1 resulted in maximum grain yield, but it was significantly at par with the grain yield produced by D_2 which in turn significantly at par with the grain yield produced by D_3. The grain yield of cultivar PR 124 was significantly higher than the cultivar PR 118. The grain yield of cultivar PR115 was significantly low as compared to PR124 and PR118.
- **Trend analysis of accumulated growing degree days of rice under transplanting window I, II and III**
  - **a)** It was observed that there was increasing trend of accumulated growing degree days (AGDD) in all the districts except the Ludhiana and Bathinda where no such prominent increasing trend was found.
  - **b)** Among all the districts, the highest rate of AGDD increased was observed in S.B.S. Nagar followed by Rupnagar. The lowest rate of increase was observed in Ludhiana and Bathinda.
- **Variability of accumulated growing degree days to complete different phenological stages of rice during different pentads under transplanting window I, II, III.**
  - **a) North east region:** Highest heat units by rice was accumulated at Hoshiarpur during the period P1(1990-1994) to P4 (2005-2009). During the next two pentads P5 and P6 the pattern shifted to S.B.S.Nagar. In case of lowest GDD accumulation the pattern was reversed.
  - **b) Central region**: Rice at district Moga had accumulated maximum GDD during all the pentads. The lowest was accumulated at Fatehgarh Sahib from P1(1990-1994) to P4(2005-2009) followed by Jalandhar in P5(2010-2014) and Ludhiana in P6 (2015-2019).
  - **c) South west region:** Muktsar showed maximum accumulation of heat unit and Bathinda lowest heat units accumulation during period all the pentads.

  Comparing the districts, overall highest heat units by the rice was accumulated at Muktsar during period P1(1990-1994) to P6 (2015-2019) to reach physiological maturity. The lowest heat units were accumulated at SBSN from pentad P1(1990-1994) to P4(2005-2009) and at Jalandhar in P5(2010-2014) and at Ludhiana in P6 (2015-2019).

- **Trend analysis of heat use efficiency (HUE) of rice from 1990-2018**
  - **a) Transplanting window I**: Among all the districts the highest rate of increase in HUE was observed at Ludhiana followed by Bathinda. The decreasing rate was found at Rupnagar, S.B.S. Nagar and Amritsar.
  - **b) Transplanting window II and III:** Highest rate of increase in HUE was observed in Ludhiana followed by Bathinda and decreasing rate at Rupnagar and Amritsar.
- **Variability in heat use efficiency (HUE) of rice in Punjab during different pentads:** It was found that maximum variability in HUE was found during P4 (2005-2009) period and minimum variability was found during P2 (1995-1999) pentad under all transplanting windows.
- **Spatio-temporal interpolation of variability of thermal requirements of rice in different districts of Punjab have been demarcated using geospatial technology**
  - **a) Transplanting Window I (1990-1994 to 2015-2019):** In the North east region AGDD changed from 1900-2100ºC day to 2300-2500ºC day in Gurdaspur, Hoshiarpur and in major portion of Rupnagar district. In major portion of S.B.S.Nagar, it changed from 1700-1900ºC day to 2300-2500ºC day. In the central region, major portion of Amritsar, Moga and Sangrur AGDD changed from 2100-2300ºC day to 2300-2500ºC day. In Patiala, Kapurthala, Jalandhar, Fatehgarh Sahib and major portion of Ludhiana, AGDD changed from 1900-2100 to 2300-2500ºC day except Ludhiana. In the South West region mainly in Faridkot, Firozpur, Mansa, Muktsar and Bathinda, heat unit accumulation changed from 2100-2300ºC day to 2300-2500ºC day except Bathinda (2100-2300ºC day).
  - **b) Transplanting Window II (1990-1994 to 2015-2019):** In the north east districts the AGDD changed from 1700-1900ºC day to 2100-2300ºC day. In central region heat unit accumulation changed from 1900-2100 to 2100-2300ºC day in Amritsar, major portion of Ludhiana, Kaputhala, Jalandhar, Moga and Sangrur. The AGDD in district Fatehgarh Sahib and Patiala changed from 1700-1900ºC day to 2100-2300ºC day. In south-west districts, AGDD changed from 1900-2100 to 2100-2300ºC day except in small portion of Mansa, Muktsar and Faridkot where it changed to 2300-2500ºC day.
  - **c) Transplanting Window III (1990-1994 to 2015-2019):** North east – In Gurdaspur and Hoshiarpur AGDD changed from 1700-1900 to 1900-2100ºC day. In major portion of S.B.S. Nagar AGDD changed from 1500-1700 to 2100-2300ºC day and in major portion of Rupnagar from 1700-1900 to 2100-2300ºC day. In central region - AGDD shifted from 1700-1900ºC day to 2100-2300°C day in Kapurthala, Jalandhar, Fatehgarh Sahib, Patiala and major portion of Sangrur Except Amritsar and Ludhiana.

However, in Moga AGDD vary from 1900-2100 to 2100-2300ºC day. In south west region, in all districts AGDD vary from 1900-2100 to 2100-2300ºC day except in Bathinda where AGDD remain 1900-2100ºC day.

- **Validation of historical thermal requirements with actual experimental data under staggered transplanting**

Transplanting Window I		
Most positive deviation		
Maximum tillering (18.15)	P3 (2000-2004)	S.B.S Nagar
Anthesis (18.50)	P2 (1995-1999)	S.B.S Nagar
Physiological maturity (20.51)	P2 (1995-1999)	S.B.S Nagar
Most negative deviation		
Maximum tillering (- 12.68)	P6 (2015-2019)	Muktsar
Anthesis (- 12.07)	P6 (2015-2019)	Muktsar
Physiological maturity (- 10.25)	P6 (2015-2019)	Muktsar

Transplanting Window II		
Most positive deviation		
Maximum tillering (25.57)	P3 (2000-2004)	Hoshiarpur
Anthesis (20.12)	P2 (1995-1999)	S.B.S Nagar
Physiological maturity (20.94)	P1(1990-1994)	S.B.S Nagar
Most negative deviation		
Maximum tillering (-9.60)	P6 (2015-2019)	Muktsar
Anthesis (- 9.96)	P6 (2015-2019)	Muktsar
Physiological maturity (- 9.58)	P6 (2015-2019)	Muktsar

Transplanting Window III		
Most positive deviation		
Maximum tillering (18.19)	P1(1990-1994)	S.B.S Nagar
Anthesis (20.56)	P2 (1995-1999)	S.B.S Nagar
Physiological maturity (21.01)	P1(1990-1994)	S.B.S Nagar
Most negative deviation		
Maximum tillering (- 9.46)	P6 (2015-2019)	Muktsar
Anthesis (- 9.58)	P6 (2015-2019)	Muktsar
Physiological maturity (- 10.19)	P6 (2015-2019)	Muktsar

- **Predicted temporal variability in thermal requirements of rice as affected by transplanting windows5**

Transplanting Window I		
Most positive deviation		
Maximum tillering (20.9)	F6 (2045-2049)	Muktsar
Anthesis (19.9)	F6 (2045-2049)	Muktsar
Physiological maturity (18)	F6 (2045-2049)	Muktsar
Lowest deviation		
Maximum tillering (9.6)	F1(2020-2024)	Hoshiarpur
Anthesis (7.2)	F1(2020-2024)	Hoshiarpur
Physiological maturity (5.4)	F1(2020-2024)	Hoshiarpur

Transplanting Window II		
Most positive deviation		
Maximum tillering (16.9)	F6 (2045-2049)	Muktsar
Anthesis (17.2)	F6 (2045-2049)	Muktsar
Physiological maturity (17.2)	F6 (2045-2049)	Muktsar
Lowest deviation		
Maximum tillering (4.5)	F1(2020-2024)	Hoshiarpur
Anthesis (2.4)	F1(2020-2024)	Gurdaspur
Physiological maturity (4.4)	F1(2020-2024)	Hoshiarpur

Transplanting Window III		
Most positive deviation		
Maximum tillering (16.7)	F6 (2045-2049)	Muktsar
Anthesis (16.8)	F6 (2045-2049)	Muktsar
Physiological maturity (18)	F6 (2045-2049)	Muktsar
Lowest deviation		
Maximum tillering (3.4)	F1(2020-2024)	Hoshiarpur
Anthesis (3.6)	F1(2020-2024)	Hoshiarpur
Physiological maturity (5.3)	F1(2020-2024)	Hoshiarpur

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