Journal of Pure and Applied Agriculture (2026) 11(1): 32-41
ISSN (Print) 2617-8672, ISSN (Online) 2617-8680
http://jpaa.aiou.edu.pk/

Evaluation of climate-resilient and profitable cropping system under semi-arid agro-ecological conditions of Khanewal, Pakistan

Saba Iqbal[1]*, Muhammad Iqbal[1], Naveed Akhtar[2], Arbab Jahangeer[1], Muhammad Arshad[1], Asmat Ullah[3], Tahira Tabassum[2], Ali Zohaib[2], Nauman Ali[2] and Siraj Ahmad[3]

[1]Agronomic Research Station, Khanewal, Pakistan
[2]Agronomic Research Institute, Faisalabad, Pakistan
[3]Agronomic Research Station, Karor (Layyah), Pakistan

*Corresponding author: Saba Iqbal (sabaiqbal87@gmail.com)

Abstract

Cotton-Wheat cropping system has long been the prevailing agricultural practice in many irrigated regions of South Punjab, Pakistan. However, due to rising input costs and increasing climate variability, its profitability and sustainability have declined over time. In response to these challenges, this study was designed to identify high climate-resilient, more profitable and resource-efficient cropping systems as alternatives for better livelihood of the regional farming community. This study evaluated the economic and system performance of thirteen cropping systems involving wheat-, canola-, and berseem-based rotations under irrigated conditions. Key indicators were assessed to figure out system sustainability. These were: benefit-cost ratio, system profitability (PKR/ha/day), system productivity (kg/ha/day), land use efficiency (%), relative economic efficiency (%) and heat use efficiency (kg/ha/°C). The results revealed substantial variation among different cropping systems. Among wheat-based systems, mungbean-wheat followed by sesame-wheat emerged as the most profitable and efficient, outperforming rice-wheat and maize-wheat. In canola-based systems cotton-canola showed relatively better results in terms of profitability and efficiency. For berseem-based systems, cotton-berseem and sesame-berseem proved to be highly profitable and resource-efficient. In terms of heat use efficiency, among the wheat-based systems, maize-wheat recorded the highest heat use efficiency. For canola-based systems, maize-canola exhibited the highest heat use efficiency. Similarly, among the berseem-based systems, maize-berseem again showed superior thermal efficiency. The data showed that mungbean wheat, sesame-wheat, cotton-canola and cotton-berseem are better cropping systems for the Khanewal, South Punjab region and are recommended as the most viable cropping systems in view of maximizing profitability and resource efficiency under changing climate scenario.

Keywords: Economic analysis, Land use efficiency, Profitability, Productivity, Sustainable agriculture

To cite this article: Iqbal, S., Iqbal, M., Akhtar, N., Jahangeer, A., Arshad, M., Ullah, A., Tabassum, T., Zohaib, A., Ali, N., & Ahmad, S. (2026). Evaluation of climate-resilient and profitable cropping system under semi-arid agro-ecological conditions of Khanewal, Pakistan. *Journal of Pure and Applied Agriculture, 11*(1), 32-41.

Introduction

South Punjab is an agricultural and industrial keystone of Pakistan (Ali et al., 2022). The agriculture division adds almost 24% to the gross domestic production (GDP) of agricultural based economy of Pakistan and 37% of the labour is involved in the agricultural sector (Economic Survey of Pakistan, 2023-24). Nonetheless the Punjab's agriculture sector has a considerable involvement to overall economy of Pakistan; it is under the pressure of foremost impacts induced by climate change such as droughts, floods and extreme temperatures (Yila et al., 2023). Two key crops grown in Punjab that have a vital contribution to the economy of Pakistan are wheat and cotton. In Pakistan, cotton; which is also known as white gold, contributes largely to the export revenue earned by the country (Rehman et al., 2019). Whereas wheat, which is also another major crop of the country, contributes approximately 10.3% of the agrarian economy as well as 2.2% of the country's overall GDP (Usman, 2016).

In South Punjab, the cotton-wheat cropping system; a prevailing cropping system of the region, has been significantly impacted by climate change. This has been resulted in considerable decline in the profitability of the farmers who are following this cropping system (Siddiqui et al., 2012). Among main constraints is the rise in temperature with frequent heat waves are adversely affecting the growth stages of crops (Ghanem, 2010; Noroz et al., 2021; Omokhafe et al., 2024; Tran et al., 2025). In cotton, high temperature badly affects flowering as well as boll formation stages and results into boll shedding and reduced fibre quality (Saini et al., 2023). Similarly, climate change–driven increases in global temperatures are adversely affecting wheat production worldwide (Singh, 2024). As a cool-season cereal, wheat is highly vulnerable to high-temperature stress, especially during critical growth phases such as germination, flowering and grain development (Singh, 2024). Exposure to elevated temperatures disrupts both physiological and reproductive functions which results in lower germination rates, reduced tiller formation, decreased pollen fertility and shortened grain-filling periods, ultimately leading to yield losses (Singh, 2024). Erratic rainfall patterns further exacerbate the situation; with water stress or unexpected heavy rainfall negatively influence the crop development (Vijai et al., 2023).

Another major issue is the rise in incidence of pests and diseases, driven by warmer and more humid conditions (Alfizar & Nasution, 2024). Pests such as whiteflies and bollworms have become more prevalent in cotton fields which not only increase the need for pesticide use but also drive up the production costs (Nagaraj et al., 2024). Wheat is also gradually more affected by rust diseases, which flourish under changing climatic conditions (Aloyce, 2025). Water scarcity, as a result of decline in canal water availability and over-extraction of groundwater, adds to the stress on crops, especially for cotton, which is highly water-intensive (Ingrao et al., 2023). Farmers are often forced to rely on expensive tube well irrigation which further reduces profit margins. Shah et al. (2016) reported that climate change has adversely influenced the profitability of the cotton–wheat cropping system in Pakistan by reduction in cotton yields due to increased heat stress and higher input costs (e.g., irrigation and pest control). Moreover the 4–6 weeks of sowing delays between wheat harvests and sowing of BT cotton further limits yield potential. Bashir et al. (2020) also reported that despite importance of cotton as a cash crop, the cotton-wheat zone remains one of the poorest in Pakistan. Economic analysis from Vehari district showed a less benefit-cost ratio (BCR) of 1.14 which indicates reduced profitability over time.

Additionally, climate change has also contributed to soil degradation as well as increased salinity and erosion, which not only reduces soil fertility but also reduces the effectiveness of fertilizers (Oishy et al., 2025). As a result of these environmental stresses, the cotton-wheat cropping system is no longer yielding the economic returns it once did. Cotton yields have shown a declining trend in recent years, while production costs, particularly for pesticides, irrigation and fertilizers, have increased sharply. Many farmers are experiencing reduced profitability or even economic losses, making the traditional system unsustainable under current climatic conditions. These challenges have led some farmers to abandon the traditional cotton-wheat rotation in favour of more lucrative or resilient crops such as maize, raya/canola, sesame or rice. This calls for an urgent re-evaluation of prevailing cropping choices in the region. Hence in the face of changing climatic scenarios, there is a growing need to explore alternative cropping systems that are not only resilient to climate stressors but also economically viable. Cropping system diversification, introduction of climate-smart practices and adoption of less water-intensive, heat-tolerant crops could potentially offer sustainable solutions (Londono, 2023). Cropping system diversification is a key strategy for increasing farm profitability, improving soil health and reducing production risks associated with mono-cropping (Mihrete & Mihretu, 2025). Introducing leguminous and oilseed crops, optimizing crop rotations and selecting crops suited to the local agro-climatic conditions can enhance system productivity while conserving resources. Khanewal, located in the cotton-wheat zone of Punjab, offers a diverse agro-ecological environment suitable for multiple cropping options beyond the conventional ones.

Although several studies have reported the adverse effects of climate change on individual crops such as cotton and wheat, limited research has comprehensively evaluated alternative cropping systems under the agro-ecological conditions of Khanewal, South Punjab, Pakistan. Comparative information on the profitability, productivity, resource-use efficiency and climate resilience of diversified wheat-, canola-, and berseem-based cropping systems is scarce. Therefore, a systematic assessment of alternative cropping systems is needed to identify economically viable and climate-resilient options for sustainable agricultural production in the region. It was hypothesized that diversified cropping systems would differ significantly in their productivity, profitability and resource-use efficiency and that systems incorporating legumes and oilseed crops would outperform the conventional cotton–wheat system in terms of overall economic returns and system performance. This study was therefore initiated to evaluate and compare the profitability, productivity and land use efficiency of thirteen different cropping systems under the agro-ecological conditions of Khanewal. The results of this study were expected to provide practical recommendations for farmers and policymakers to enhance farm income improve input use efficiency and promote sustainable agricultural practices in the region.

Material and Methods

The experiment was conducted at the Agronomic Research Station, Khanewal, located in the semi-arid region of Southern Punjab, Pakistan. The study spanned for four consecutive years (2020-21 to 2023-24) to undergo seasonal variations and ensure reliability of the data set.

Experimental design and treatments

The study was laid out in a randomized complete block design (RCBD) with three replications. Thirteen cropping systems (CS) were evaluated, each treatment represent a complete annual cropping sequence. The treatments were: CS1: Cotton – Wheat; CS2: Rice – Wheat; CS3: Maize – Wheat; CS4: Sesame – Wheat; CS5: Mungbean – Wheat; CS6: Cotton – Canola; CS7: Rice – Canola; CS8: Maize – Canola; CS9: Sesame – Canola; CS10: Cotton – Berseem; CS11: Rice – Berseem; CS12: Maize – Berseem; CS13: Sesame – Berseem. Berseem was grown as fodder crop. Each cropping system was allotted a plot size of 20 m × 10 m (200 m²).

Crop husbandry

Each crop in the system was cultivated as per its standard agronomic recommendations suitable for Khanewal agro-ecological conditions. The field was prepared by conventional tillage, comprising two cultivations, one laser levelling and one deep ploughing followed by planking to achieve a fine tilth. Sowing of crops was done using appropriate methods, i.e., drilling for wheat, mungbean and canola; manual dibbling for maize, sesame and cotton while broadcasting for berseem and transplanting for rice. Sowing times of each crop in each cropping system has been presented in Table 1. Certified seed of recommended varieties was used. Cotton variety MNH-1026, wheat variety Johar-2016, rice variety PK-1121, maize variety Sahiwal Gold, sesame variety TS-3, mungbean variety AZRI-mung and canola variety AARI-Canola was used. Crop-specific seed rates were maintained, i.e. cotton: 15 kg/ha; wheat: 125 kg/ha; rice: 17 kg/ha (nursery), transplanted at 3 seedlings per hill; maize: 25 kg/ha; sesame: 5 kg/ha; canola: 5 kg/ha; berseem: 20 kg/ha; mungbean: 30 kg/ha. Fertilizers were applied at recommended doses using urea, DAP and SOP as sources; for cotton (247: 99: 94 NPK kg/ha), for wheat (158: 114: 64 NPK kg/ha), for rice (62: 86: 136 NPK kg/ha), for maize (294: 170: 123 NPK kg/ha), for sesame (84: 57: 62 NPK kg/ha), for mungbean (22: 57: 30 NPK kg/ha) and for canola (86: 74: 30 NPK kg/ha). Irrigation was applied at critical crop growth stages according to crop water requirements, using surface irrigation methods. For cotton 18 irrigations, for wheat 4 irrigations, for rice, plots were kept flooded during first thirty-five days of transplanting and afterwards 8 irrigations, for maize 12 irrigations, for sesame 3 irrigations, for mungbean 3 irrigations and for canola 3 irrigations were applied as per the weather conditions and crop requirement. Appropriate herbicides and manual weeding were used for weed control. Pesticides and fungicides were applied based on crop monitoring and threshold levels to manage insect-pests and diseases. Crops were harvested at harvest maturity. Manual harvesting was followed by threshing, drying, cleaning and weighing of produce. Four cuts of berseem were taken when the crop reached to appropriate height.

Data collection

At maturity, each crop in all cropping systems was harvested manually. Post-harvest threshing was performed using thresher to extract grain. The harvested produce was weighed to determine crop-wise and system-wise yields. The following observations were recorded to appraise the performance and profitability of various cropping systems.

a. Economic analysis

The cost of production was calculated as follow:
Cost of production (PKR/ha) = Input costs incurred during cropping period
Gross income was calculated as follow:
Gross income (PKR/ha) = Total market value of produce
Net income was calculated as follow:
Net Income (PKR/ha) = Cost of production − Gross income
The BCR was computed as follow:

$$BCR = \frac{Gross\ income}{Cost\ of\ production}$$

b. System performance

The system performance was assessed using system profitability (PKR/ha/day) indices which was calculated by dividing the net income by the total duration of the cropping sequence in days (Mohanta et al., 2021), thus normalizing profit over time. System productivity (kg/ha/day) was calculated by summing the yields of the kharif and rabi crops, both expressed in kilograms per hectare, and then dividing the total by the duration of the entire cropping system in days (Sharma et al., 2015). This provided a measure of the average daily productivity of the system in terms of kilograms per hectare per day. Land Use Efficiency (LUE %) was determined by adding the duration (in days) of both the kharif and rabi crops, dividing the total by 365 (the number of days in a year), and then multiplying the result by 100 (Ngangom et al., 2020). This expresses the proportion of the year during which land and resources were actively utilized for crop production, as a percentage. Similarly, relative economic efficiency (REE %) was computed by the comparison of the net returns of each system to the prevailing cotton-wheat cropping system (Chitale et al., 2011) to express the economic superiority or inferiority as a percentage. Heat use efficiency (HUE) was determined through division of the crop yield (in kilograms per hectare) by the accumulated growing degree days (°C day) during the crop growth period (Nandini & Sridhara, 2019).

Weather conditions at the experimental site

The experimental site experienced a typical subtropical climate characterized by hot summers and cool winters (Fig. 1). Over the four-year period (2020-21–2023-24), the average maximum temperatures ranged from approximately 13°C in winter (January) to over 46°C in peak summer (June). The highest average maximum temperature was recorded in June 2024 (46.09°C). The average minimum temperatures ranged from about 3°C to 29°C, with the lowest temperatures recorded in January and February, and the highest in July and August. The warmest nights were observed in July and August of 2024, with minimum temperatures higher than 29°C that suggests high nighttime heat stress during the kharif season. Rainfall was highly variable across months and years. Annual rainfall ranged from a low of 59 mm in 2021 to a high of 289 mm in 2023. The monsoon months, particularly July to September, contributed the majority of the precipitation, while the highest monthly rainfall (149.7 mm) was recorded in August 2024 over the four years. Some years, such as 2020 and 2024, experienced intense but sporadic rainfall, while 2021 was markedly dry.

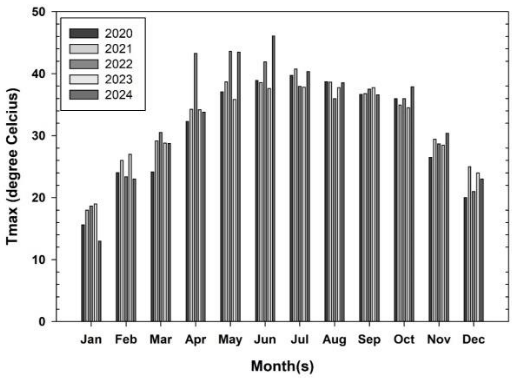
Table 1 Date of sowing and harvesting of crops

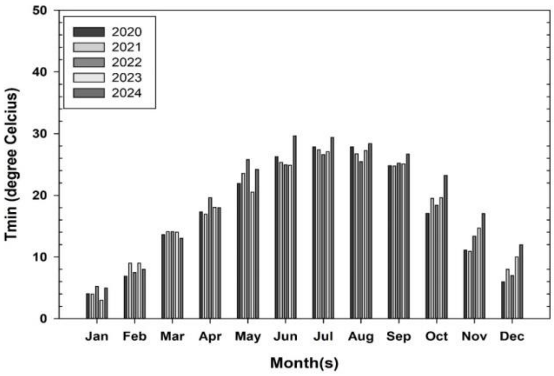
Cropping system	2020-2021				2021-2022				2022-2023				2023-2024			
	Summer		Winter		Summer		Winter		Summer		Winter		Summer		Winter	
	D.O.S.	D.O.H.	D.O.S.	D.O.H.	D.O.S.	D.O.H.	D.O.S.	D.O.H.	D.O.S.	D.O.H.	D.O.S.	D.O.H.	D.O.S.	D.O.H.	D.O.S.	D.O.H.
Cotton-Wheat	25 Apr.	25 Oct.	7 Nov.	15 Apr.	25 Apr.	25 Oct.	7 Nov.	15 Apr.	25 Apr.	25 Oct.	7 Nov.	15 Apr.	25 Apr.	25 Oct.	7 Nov.	15 Apr.
Rice-Wheat	5 July	25 Oct.	13 Nov.	15 Apr.	5 July	25 Oct.	13 Nov.	15 Apr.	5 July	25 Oct.	13 Nov.	15 Apr.	5 July	25 Oct.	13 Nov.	15 Apr.
Maize-Wheat	26 July	15 Nov.	24 Nov.	15 Apr.	26 July	15 Nov.	24 Nov.	15 Apr.	26 July	15 Nov.	24 Nov.	15 Apr.	26 July	15 Nov.	24 Nov.	15 Apr.
Sesame-Wheat	2 May	14 Aug.	27 Oct.	15 Apr.	2 May	14 Aug.	27 Oct.	15 Apr.	2 May	14 Aug.	27 Oct.	15 Apr.	2 May	14 Aug.	27 Oct.	15 Apr.
Cotton-Canola	1 Apr.	10 Oct.	20 Oct.	20 Mar.	1 Apr.	10 Oct.	20 Oct.	20 Mar.	1 Apr.	10 Oct.	20 Oct.	20 Mar.	1 Apr.	10 Oct.	20 Oct.	20 Mar.
Rice-Canola	5 July	25 Oct.	3 Nov.	20 Mar.	5 July	25 Oct.	3 Nov.	20 Mar.	5 July	25 Oct.	3 Nov.	20 Mar.	5 July	25 Oct.	3 Nov.	20 Mar.
Maize-Canola	26 July	15 Nov.	20 Nov.	20 Mar.	26 July	15 Nov.	20 Nov.	20 Mar.	26 July	15 Nov.	20 Nov.	20 Mar.	26 July	15 Nov.	20 Nov.	20 Mar.
Sesame-Canola	2 May	14 Aug.	15 Oct.	20 Mar.	2 May	14 Aug.	15 Oct.	20 Mar.	2 May	14 Aug.	15 Oct.	20 Mar.	2 May	14 Aug.	15 Oct.	20 Mar.
Cotton-Berseem	1 Apr.	10 Oct.	17 Oct.	20 Mar.	1 Apr.	10 Oct.	17 Oct.	20 Mar.	1 Apr.	10 Oct.	17 Oct.	20 Mar.	1 Apr.	10 Oct.	17 Oct.	20 Mar.
Rice-Berseem	5 July	25 Oct.	28 Oct.	5 Apr.	5 July	25 Oct.	28 Oct.	5 Apr.	5 July	25 Oct.	28 Oct.	5 Apr.	5 July	25 Oct.	28 Oct.	5 Apr.
Maize-Berseem	26 July	15 Nov.	20 Nov.	5 Apr.	26 July	15 Nov.	20 Nov.	5 Apr.	26 July	15 Nov.	20 Nov.	5 Apr.	26 July	15 Nov.	20 Nov.	5 Apr.
Sesame-Berseem	2 May	14 Aug.	15 Oct.	5 Apr.	2 May	14 Aug.	15 Oct.	5 Apr.	2 May	14 Aug.	15 Oct.	5 Apr.	2 May	14 Aug.	15 Oct.	5 Apr.
Mungbean-Wheat	28 Apr.	25 Aug.	28 Oct.	15 Apr.	28 Apr.	25 Aug.	28 Oct.	15 Apr.	28 Apr.	25 Aug.	28 Oct.	15 Apr.	28 Apr.	25 Aug.	28 Oct.	15 Apr.

*D.O.S = Date of sowing; D.O.H.= Date of harvesting

Statistical analysis

The data on economic returns and system performance collected over four years were subjected to statistical analysis using appropriate techniques to determine the significance of differences among the cropping systems. Data were analysed as a sum of four-year to capture seasonal effects and evaluate long-term trends and stability of each cropping system. Analysis of variance (ANOVA) was performed to evaluate the significance of differences among the thirteen cropping systems for yield and economic parameters using statistical software, Statistix 8.1. The means were compared using least significant difference (LSD) test at 5% probability level to separate statistically distinct cropping systems. Microsoft Excel was used for tabulation and graphical representation of results.





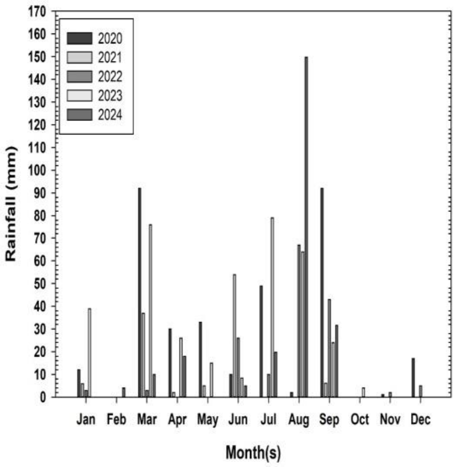


Fig. 1 Weather conditions at the experimental site (2020-21 and 2023-24)

Results

Economic analysis

In the analysis of various cropping systems, the wheat-based cropping system demonstrated significant difference in COP, gross income, net income and BCR. Among these systems, the highest COP was observed in the cotton-wheat system, followed by the maize-wheat system (Fig. 2). In contrast, the lowest COP was found in the sesame-wheat system (Fig. 2). When considering gross income, the highest gross income was generated by the rice-wheat system, closely followed by the cotton-wheat system (Fig. 3). On the other hand, the lowest gross income was recorded in the maize-wheat system. In terms of net income, the highest net income was achieved by the mungbean-wheat system (Fig. 4). Conversely, the lowest net income was observed in the maize-wheat system (Fig. 4). Finally, the highest BCR was seen in the mungbean-wheat system (Fig. 5). The lowest BCR was found in the maize-wheat system (Fig. 5).

In the canola-based cropping systems, the economic performance also varied significantly across the different combinations of crops. The highest COP was recorded in the cotton-canola system, followed by the maize-canola system (Fig. 2). In contrast, the lowest COP was found in the sesame-canola system (Fig. 2). Regarding gross income, the highest gross income was generated by the cotton-canola system, closely followed by the rice-canola system. On the other hand, the lowest gross income was recorded in the maize-canola system (Fig. 3). For net income, the highest net income was observed in the cotton-canola system, followed by the sesame-canola system (Fig. 4). The lowest net income was found in the maize-canola system (Fig. 4). Finally, in terms of BCR, the highest BCR was achieved by the cotton-canola system (Fig. 5). The lowest BCR was observed in the maize-canola system (Fig. 5).

In the berseem-based cropping systems, performance metrics varied significantly across the different crop combinations. The highest COP was recorded in the cotton-berseem system, followed closely by the maize-berseem system (Fig. 2). The lowest COP was found in the sesame-berseem system (Fig. 2). Regarding gross income, the highest gross income was generated by the cotton-berseem system, followed by the sesame-berseem system (Fig. 3). The lowest gross income was recorded in the maize-berseem system (Fig. 3). For net income, the highest net income was achieved by the cotton-berseem system (Fig. 4). In contrast, the lowest net income was seen in the maize-berseem system. The sesame-berseem system performed relatively well. Finally, in terms of BCR, the highest BCR was observed in the sesame-berseem system, followed closely by the cotton-berseem system. The lowest BCR was found in the maize-berseem system (Fig. 5).

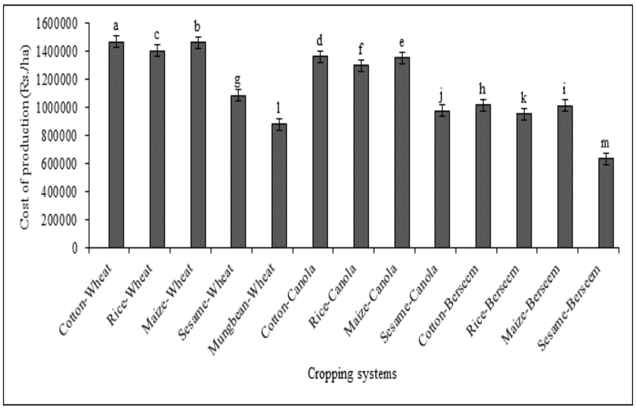


Fig. 2 Cost of production of various cropping systems under agro-ecological conditions of Khanewal from 2020-21 to 2023-24

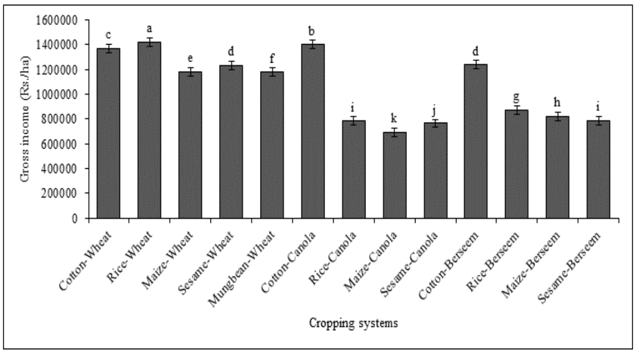


Fig. 3 Gross income of various cropping systems under agro-ecological conditions of Khanewal from 2020-21 to 2023-24

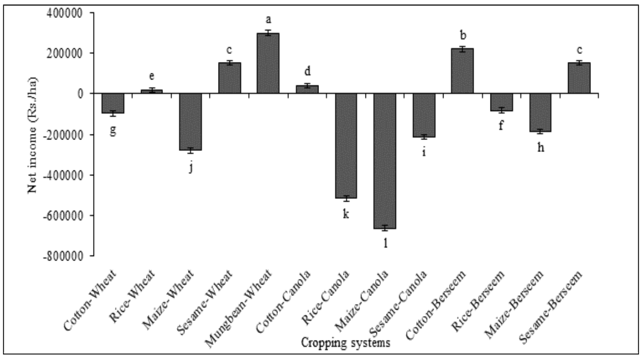


Fig. 4 Net income of various cropping systems under agro-ecological conditions of Khanewal from 2020-21 to 2023-24

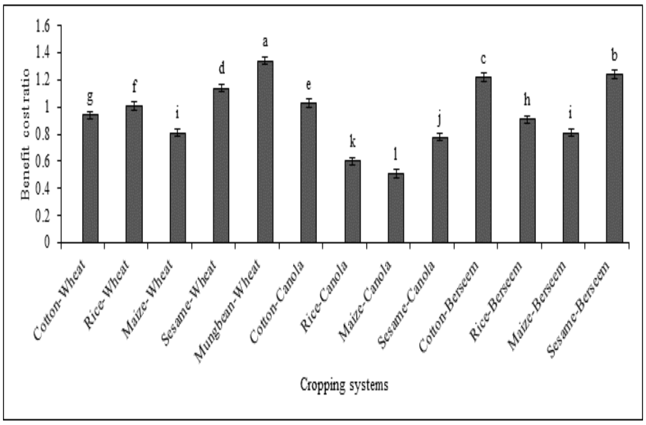


Fig. 5 Benefit cost ratio of various cropping systems under agro-ecological conditions of Khanewal from 2020-21 to 2023-24

System performance

In the analysis of system performance, various cropping systems differed significantly for system profitability and relative economic efficiency while differed non-significantly for system productivity and land use efficiency. In the wheat based cropping systems, the highest system profitability was observed in the mungbean-wheat and sesame-wheat system (Table 2), followed by the rice-wheat system. The lowest system profitability was recorded in the maize-wheat system (Table 2). The highest relative economic efficiency was recorded in the mungbean-wheat system followed by the sesame-wheat system. The lowest relative economic efficiency was found in the maize-wheat system. In the canola based cropping systems, the highest system profitability was observed in the cotton-canola system (Table 2). The lowest system profitability was seen in the maize-canola system (Table 2). The highest relative economic efficiency was observed in the cotton-canola system, followed by the sesame-canola system (Table 2). The lowest relative economic efficiency was recorded in the maize-canola system (Table 2).

Moreover, in berseem based cropping system, the highest system profitability was recorded in the cotton-berseem system, followed by the sesame-berseem system. The lowest system profitability was observed in the maize-berseem system (Table 2). The highest relative economic efficiency was seen in the cotton-berseem system followed by the sesame-berseem system. The lowest relative economic efficiency was observed in the maize-berseem system (Table 2). Among the wheat-based systems, maize-wheat recorded the highest HUE followed by rice-wheat and sesame-wheat, while cotton-wheat had the lowest (Fig. 6). For canola-based systems, maize-canola exhibited the highest HUE, with sesame-canola showing the lowest. Similarly, among the berseem-based systems, maize-berseem again showed superior thermal efficiency, whereas sesame-berseem recorded the lowest HUE value (Fig. 6).

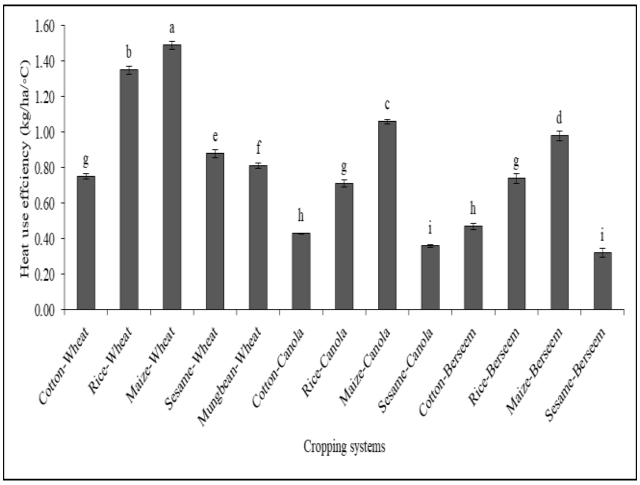


Fig. 6 Heat use efficiency of various cropping systems under agro-ecological conditions of Khanewal from 2020-21 to 2023-24

Table 2 System profitability, system productivity, land use efficiency and relative economic efficiency of various cropping systems under agro-ecological conditions of Khanewal

Cropping System	System Profitability (PKR/ha/day)	System Productivity (kg/ha/day)	Land use efficiency (%)	Relative economic efficiency (%)
Cotton-Wheat	-260 g	13	94	-
Rice-Wheat	51 e	22	101	120 b-e
Maize-Wheat	-761 j	24	81	-192 f
Sesame-Wheat	412 c	14	114	258 abc
Mungbean-Wheat	819 a	14	134	414 a
Cotton-Canola	111 d	11	103	142 bcd
Rice-Canola	-1411 k	9	60	-441 f
Maize-Canola	-1811 l	10	51	-594 g
Sesame-Canola	-577 i	6	78	-121 f
Cotton-Berseem	604 b	8	122	331 ab
Rice-Berseem	-223 f	10	91	15 c-f
Maize-Berseem	-514 h	11	81	-97 ef
Sesame-Berseem	414 c	6	124	259 ab
LSD 0.05	17	NS	NS	240

*Figures having same case letter do not differ significantly at $p \leq 0.05$

Discussion

The comparative analysis of wheat-, canola- and berseem-based cropping systems revealed substantial differences in economic and cropping system performance indicators, offering insights into system sustainability and profitability. Wheat-based systems demonstrated a wide range of performance. The mungbean-wheat and sesame-wheat systems stood out with high system profitability and relative economic efficiency indicating its strong potential as a profitable and resource-efficient option. The rice-wheat system showed moderate profitability suggesting its competitiveness in terms of yield and economic return. In contrast, the maize-wheat system was the least efficient and profitable, with negative profitability and the lowest relative economic efficiency despite having the highest productivity. This indicates that yield alone does not guarantee profitability, especially when production costs are high. One of the primary benefits of the mungbean-wheat and sesame–wheat systems are the lower cost of production associated with mungbean and sesame cultivation. Secondly, the early harvesting of mungbean and sesame created a favourable window for the timely sowing of wheat, which is critical for achieving optimum wheat yields. Moreover legume–cereal cropping sequences generally outperform cereal–cereal systems because of complementary nutrient use patterns and improved soil fertility (Liu et al., 2023, Wang et al., 2025). This is mainly attributed to the contribution of legumes in fixing atmospheric nitrogen and enriching the soil through biological nitrogen fixation and nutrient-rich root exudates (rhizodeposition) (Liu et al., 2024). Hussain et al., 2013 reported that in South Asia containing Pakistan, the key yield preventive limitation in cotton-wheat and rice-wheat cropping system is delayed wheat planting. In areas where these cropping systems are followed the major portion of the wheat, approximately 70%, is sown after the harvesting of rice and cotton whereas the late harvesting of basmati rice varieties as well as late pickings of cotton results in delay in sowing of wheat (Hussain et al., 2013; Ali et al., 2021).

In many studies it has been reported that late sowing results in consider able reduction in days to grain filling duration as well as days to maturity hence ultimately results in yield reduction (Farooq et al., 2011). Anwar et al. (2013) also reported that sesame completes its cycle within 100-110 days hence categorised as a short duration crop. It can be adjusted as a catch crop in Zaid Kharif hence timely planting of wheat can be achieved after sesame crop. Furthermore, they also described that sesame is a better cash crop due to its better sale price, higher demand and conversely lower cost of production. Moreover, it is sold easily in market hence farmers not to face any hurdle in its marketing (Anwar et al., 2013). This results in reduced monetary load and more availability for resource-constrained farmers. Hence after evaluation of these agronomic, economic and ecological benefits, the mungbean-wheat and sesame–wheat cropping systems stand out as a sustainable and profitable choice for diversification and intensification in wheat-based regions.

Among canola-based systems the cotton-canola system emerged as the most favourable among canola combinations and relative economic efficiency. In contrast, the maize-canola and rice-canola systems showed poor economic outcomes, with extremely low profitability and very low land use efficiencies. Under the changing climate scenario, the cotton–canola cropping system proves to be more advantageous compared to other canola-based systems such as rice–canola, maize–canola and sesame–canola. One of the key benefits of this system lies in its alignment with optimal sowing windows for both component crops. Climate change has significantly impacted the traditional sowing calendar of cotton that has made the late-sown cotton less productive and more susceptible to pest infestations, especially from bollworms and whiteflies (Ashraf et al., 2024). In contrast, early sowing of cotton in late March or early April has shown the potential to improve yield and reduce pest pressure due to favourable early-season conditions (Himatullah et al., 2022). The cotton–canola system accommodates this by allowing cotton to be sown early and harvested by the first week of October, which in turn enables the timely sowing of canola; a critical factor to enhance its yield potential (Butkevičienė et al., 2021). Conversely, in rice–canola and maize–canola systems, the late harvesting of rice and maize that typically extend into late October or early November, delays canola sowing and pushes it beyond its optimum window. This delay results in reduced canola yields, as the crop fails to fully exploit the available growing season and is more vulnerable to high temperatures during flowering and grain filling stages (Secchi et al., 2023). The cotton–canola rotation, therefore, offers a well-synchronized cropping calendar. It ensures that both crops are sown and harvested at their optimum times, thereby maximizing system productivity, minimizing pest pressure, and enhancing resource-use efficiency. Additionally, this system supports better land use planning and helps in spreading labour and machinery demand more evenly across the season.

Berseem-based systems showed strong potential for profitability and resource efficiency. The cotton-berseem system achieved high profitability, excellent land use efficiency and high relative economic efficiency making it a strong candidate for sustainable intensification. Similarly, the sesame-berseem system performed well and the highest land use efficiency among all systems. However, the maize-berseem system lagged behind, with negative profitability and the lowest relative economic efficiency among berseem-based systems, reflecting similar trends to the maize-wheat and maize-canola systems. The higher economic returns observed in the cotton–berseem and sesame–berseem cropping systems can be attributed primarily to the timely sowing of both component crops and the inclusion of a nitrogen-fixing legume (berseem) in the rotation. Timely sowing ensures optimal plant establishment, efficient use of available resources, and enhanced biomass production (Liu et al., 2025), which collectively contribute to improved fodder/fiber/seed yields and system profitability. Additionally, the incorporation of berseem; a well-known leguminous fodder crop, plays a significant role in restoring soil fertility by biologically fixing atmospheric nitrogen and improving soil organic matter (Kumari et al., 2023). This nutrient enhancement benefits the next crop in the sequence that leads to better growth and yield performance (Kumbhar et al., 2007). In contrast, the maize–berseem cropping system exhibits lower economic performance, largely due to the delayed sowing of berseem due to late harvest of maize. This delay shortens the effective growth period of berseem, especially during lower winter temperatures which ultimately results in reduced biomass accumulation and lower fodder yield (Singh et al., 2021). Delayed sowing in such systems leads to suboptimal utilization of the growing season and adversely affects overall system efficiency. These findings emphasize the importance of crop sequencing and rotation planning to ensure timely sowing, optimal use of biological nitrogen fixation and improved system sustainability.

Conclusion

In conclusion, the performance of wheat-, canola- and berseem-based cropping systems varied notably in terms of system profitability productivity as well as relative economic efficiency. Among the wheat-based cropping systems, mungbean wheat and sesame-wheat proved to be the most promising, with high system profitability and strong relative economic efficiency. While rice-wheat showed moderate performance, the maize-wheat system consistently underperformed economically despite its high productivity which indicates that yield alone does not ensure profitability. In the case of canola-based systems, cotton-canola system was relatively better than other combinations, showing positive profitability and acceptable efficiency metrics that makes it the most suitable option among canola-based systems. Conversely, maize-canola and rice-canola systems exhibited substantial economic losses and inefficiencies that suggest they are not economically viable under current conditions. For berseem-based systems, the cotton-berseem and sesame-berseem systems demonstrated excellent performance, with high profitability and favourable economic returns. In contrast, maize-berseem was less effective, and similar trend was seen in other maize-based combinations. Although maize-based systems showed high heat use efficiency, they were not economically viable due to their high cost of production and relatively low benefit-cost ratio. Further research is recommended to develop cost-effective management strategies and input use efficiencies for maize-based systems, so their heat use advantage can be translated into economic gains. Overall, when considering all economic and efficiency parameters, the most suitable systems recommended for farmers are mungbean-wheat, sesame-wheat from the wheat-based systems, cotton-canola from the canola-based systems and cotton-berseem from the berseem-based systems. These combinations not only maximize returns but also make efficient use of resources which makes them viable options for sustainable and profitable farming under changing climate.

Acknowledgements: This experiment was the part of Annual program of research work of Agronomic Research Station, Khanewal.

Conflict of Interest: Authors have no conflict of interest.

References

Alfizar, A., & Nasution, S. S. (2024). The explosion of pests and diseases due to climate change. *IOP Conference Series: Earth and Environmental Science, 1297*(1), Article 012072. https://doi.org/10.1088/1755-1315/1297/1/012072

Ali, K. A., Amin, S. M., & Abdullah, R. A. (2021). Late sowing date influence on wheat and triticale crop yields as a drought management tool. *Journal of the Saudi Society of Agricultural Sciences, 20*(6), 353–358.

Ali, M. A., Hassan, M., Mehmood, M., Kazmi, D. H., Chishtie, F. A., & Shahid, I. (2022). The potential impact of climate extremes on cotton and wheat crops in southern Punjab, Pakistan. *Sustainability, 14*(3), Article 1609. https://doi.org/10.3390/su14031609

Aloyce, A. A. (2025). Climate change and its impact on wheat stem rust disease dynamics in Tanzania. *Discover Agriculture, 3*, Article 43. https://doi.org/10.1007/s44279-025-00192-w

Anwar, M., Hasan, E. U., Bibi, T., Mustafa, H. S. B., Mahmood, T., & Ali, M. (2013). TH-6: A high yielding cultivar of sesame released for general cultivation in Punjab. *Advances in Life Sciences, 1*(1), 44–57.

Ashraf, S., Ch, K. M., Ashraf, I., & Akbar, N. (2024). A phenomenological inquiry into farmers' experiences growing cotton in Punjab, Pakistan. *Scientific Reports, 14*, Article 13846. https://doi.org/10.1038/s41598-024-62950-y

Bashir, M. K., Hassan, S., Ali, A., & Farooq, M. U. (2020). Where farmers stand in terms of trade of cotton production? The case of District Vehari (Punjab), Pakistan. *Pakistan Journal of Life and Social Sciences, 18*(1), 51–57.

Butkevičienė, L. M., Kriaučiūnienė, Z., Pupalienė, R., Velička, R., Kosteckienė, S., Kosteckas, R., & Klimas, E. (2021). Influence of sowing time on yield and yield components of spring rapeseed in Lithuania. *Agronomy, 11*(11), Article 2170. https://doi.org/10.3390/agronomy11112170

Chitale, S., Sarawgi, S. K., Tiwari, A., & Urkurkar, J. S. (2011). Assessment of productivity and profitability of different rice (*Oryza sativa*)-based cropping systems in Chhattisgarh plains. *Indian Journal of Agronomy, 56*(4), 305–310.

Farooq, M., Bramley, H., Palta, J. A., & Siddique, K. H. M. (2011). Heat stress in wheat during reproductive and grain filling phases. *Critical Reviews in Plant Sciences, 30*, 491–507.

Economic Survey of Pakistan. (2023-24). Finance division, Government of Pakistan.

Ghanem, H. (2010). *Addressing food insecurity in protracted crises*. Food and Agriculture Organization of the United Nations (FAO).

Himatullah, Imran, A., Khan, L. A., Mahesar, T. G., Sohaib, M., & Habib-ur-Rahman, M. (2022). Threats and challenges for sustainable cotton production in Sindh, Pakistan: Climate change vulnerability assessment and adaptation to combat climate change. *Journal of Plant and Environment, 4*(2), 211–229.

Hussain, M., Farooq, M., Shabir, G., Khan, M. B., Zia, M. A. B., & Lee, D. J. (2013). Delay in planting decreases wheat productivity. *International Journal of Agriculture and Biology, 14*(4), 533–539.

Ingrao, C., Strippoli, R., Lagioia, G., & Huisingh, D. (2023). Water scarcity in agriculture: An overview of causes, impacts and approaches for reducing the risks. *Heliyon, 9*(8), Article e18507. https://doi.org/10.1016/j.heliyon.2023.e18507

Kumari, V. V., Singh, V. K., Gopinath, K. A., Govindarajan, V., Mathyam, P., & Gajjala, R. C. (2023). Crop and livestock productivity, soil health improvement and insect dynamics: Impact of different fodder-based cropping systems in a rainfed region of India. *Agricultural Systems, 208*, Article 103646. https://doi.org/10.1016/j.agsy.2023.103646

Kumbhar, A. M., Buriro, U. A., Kumbhar, M. B., Oad, F. C., Jamro, G. H., & Chachar, Q. (2007). Yield of wheat, cotton, berseem and soybean under different crop sequences and fertility regimes. *Asian Journal of Plant Sciences, 6*(1), 143–147.

Liu, C., Feng, X., Xu, Y., Kumar, A., Yan, Z., Zhou, J., Yang, Y., Peixoto, L., Zeng, Z., & Zang, H. (2023). Legume-based rotation enhances subsequent wheat yield and maintains soil carbon storage. *Agronomy for Sustainable Development, 43*, 64.

Liu, C., Zhang, L., Zhou, J., Xu, Y., Yang, Y., Zeng, Z., & Zang, H. (2024). Research progress on the intensification of agroecosystem functions through legume-based crop rotation. *Acta Agronomica Sinica, 50*, 1885–1895.

Liu, J., Shen, Y., Zeng, C., Zhang, J., Shi, S., Xue, L., Jia, Y., Li, J., & Liang, X. (2025). Effects of sowing time on yield and quality of winter and spring wheat varieties. *Sustainability, 17*(6), 2479. https://doi.org/10.3390/su17062479

Londoño Parra, S. (2023). Diversification of cropping systems to improve national food security. *Magna Scientia UCEVA, 3*(2), 175–179.

Mihrete, T. B., & Mihretu, F. B. (2025). Crop diversification for ensuring sustainable agriculture, risk management and food security. *Global Challenges, 9*, 2400267. https://doi.org/10.1002/gch2.202400267

Mohanta, S., Banerjee, M., Malik, G. C., Shankar, T., Maitra, S., Ismail, I. A., Dessoky, E. S., Attia, A. O., & Hossain, A. (2021). Productivity and profitability of Kharif rice are influenced by crop establishment methods and nitrogen management in the lateritic belt of the subtropical region. *Agronomy, 11*(7), 1280. https://doi.org/10.3390/agronomy11071280

Nagaraj, S., Rajasekaran, R., Palaniappan, J., et al. (2024). Emerging technological developments to address pest resistance in Bt cotton. *Journal of Cotton Research, 7*, 30. https://doi.org/10.1186/s42397-024-00192-z

Nandini, K. M., & Sridhara, S. (2019). Heat use efficiency, helio thermal use efficiency and photo thermal use efficiency of foxtail millet (*Setaria italica* L.) genotypes as influenced by sowing dates under southern transition zone of Karnataka. *Journal of Pharmacognosy and Phytochemistry, SP2*, 284–290.

Ngangom, B., Das, A., Lal, R., Idapuganti, R. G., Layek, J., Basavaraj, S., Babu, S., Yadav, G. S., & Ghosh, P. K. (2020). Double mulching improves soil properties and productivity of maize-based cropping system in eastern Indian Himalayas. *International Soil and Water Conservation Research, 8*(4), 308–320.

Noroz, M. M., Shah, A. N., & Latif, A. (2021). Role of adaptation strategies for climate change and nutrients management tools in Gilgit Baltistan's agriculture. *Advances in Agriculture and Biology, 4*(1), 14-21. https://doi.org/10.63072/aab.21003

Oishy, M. N., Shemonty, N. A., Fatema, S. I., Mahbub, S., Mim, E. L., Raisa, M. B. H., & Anik, A. H. (2025). Unravelling the effects of climate change on the soil–plant–atmosphere interactions: A critical review. *Soil & Environmental Health, 3*(1), 100130.

Omokhafe, K., Dongo, L., & Imoren, E. (2024). Agricultural productivity in developing countries and influence of climate change on agriculture. *Advances in Agriculture and Biology, 7*(1), 21-28. https://doi.org/10.63072/aab.24003

Rehman, A., Jingdong, L., Chandio, A. A., Hussain, I., Wagan, S. A., & Memon, Q. U. A. (2019). Economic perspectives of cotton crop in Pakistan: A time series analysis (1970–2015) (Part 1). *Journal of the Saudi Society of Agricultural Sciences, 18*, 49–54.

Saini, D. K., Impa, S. M., McCallister, D., et al. (2023). High day and night temperatures impact on cotton yield and quality—current status and future research direction. *Journal of Cotton Research, 6*, 16. https://doi.org/10.1186/s42397-023-00154-x

Secchi, M. A., Fernandez, J. A., Stamm, M. J., Durrett, T., Prasad, P. V. V., Messina, C. D., & Ciampitti, I. A. (2023). Effects of heat and drought on canola (*Brassica napus* L.) yield, oil, and protein: A meta-analysis. *Field Crops Research, 293*, 108848. https://doi.org/10.1016/j.fcr.2023.108848

Shah, M. A., Farooq, M., & Hussain, M. (2016). Productivity and profitability of cotton–wheat system as influenced by relay intercropping of insect resistant transgenic cotton in bed planted wheat. *European Journal of Agronomy, 75*, 33–41.

Sharma, S. K., Rana, S. S., Subehia, S. K., & Negi, S. C. (2015). Production potential of rice-based cropping sequences on farmers' fields in low hills of Kangra district of Himachal Pradesh. *Himachal Journal of Agricultural Research, 41*(1), 20–24.

Siddiqui, R., Samad, G., Nasir, M., & Jalil, H. H. (2012). The impact of climate change on major agricultural crops: Evidence from Punjab, Pakistan. *Pakistan Development Review, 51*(4), 261–274.

Singh, H. (2024). Impact of high temperature on wheat (*Triticum aestivum*) crop: Review. *ShodhKosh: Journal of Visual and Performing Arts, 5*(1), 2388–2392. https://doi.org/10.29121/shodhkosh.v5.i1.2024.5269

Singh, S., Singh, K., & Kaur, T. (2021). Effect of different sowing dates and timings of last cut on yield attributes and seed yield of berseem (*Trifolium alexandrinum* L.). *Legume Research – An International Journal, 44*(5), 574–578.

Tran, B. L., Tseng, W. C., & Chen, C. C. (2025). Climate change impacts on crop yields across temperature rise thresholds and climate zones. *Scientific Reports, 15*, 23424. https://doi.org/10.1038/s41598-025-07405-8

Usman, M. (2016). Contribution of agriculture sector in the GDP growth rate of Pakistan. *Journal of Global Economics, 4*, 184.

Vijai, C., Worakamol, W., & Elayaraja, M. (2023). Climate change and its impact on agriculture. *International Journal of Agricultural Sciences and Veterinary Medicine, 11*(4). https://doi.org/10.25303/1104ijasvm0108

Wang, R., Wu, J., Wang, Y., Sun, Z., Ma, W., Xue, C., & Xu, H. (2025). Legacy effects of different preceding crops on grain yield, protein fractions and soil nutrients in subsequent winter wheat. *Plants, 14*(16), 2598. https://doi.org/10.3390/plants14162598

Yila, K. M., Gboku, M. L. S., Lebbie, M. S., & Kamara, L. I. (2023). Changes in rainfall and temperature and its impact on crop production in Moyamba District, Southern Sierra Leone. *Atmospheric and Climate Sciences, 13*(1), 19–43.