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An Economic Analysis of Sugar beet Production in Punjab, Pakistan

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ABSTRACT

Pakistan economy is based on agriculture with a vital share of 19.5% in total GDP which provide 42.3% of the total labor force. Pakistan has highest demand of sugar i.e., 25 kg per capita per annum. Cane and beet are the two major causes of sugar production in the world. Sugarcane production in the country could meet only 75% demand of existing sugar mills. In 2017, sugar beet production in Pakistan was 105,783 tonnes while it remained cultivated on a range of 2628 hectares. Present study was illustrated the economic analysis of sugar beet production in Chiniot District and identify the factors affecting the production of sugar beet. For that purpose, primary data were collected from 100 sugar beet growers from district Chiniot by using simple random sampling technique through a well-structured questionnaire for the cropping season 2018-19. The appropriate statistical and econometric method has been used to analyze the data. The multiple linear regression is used when there is more than two independent variables and one dependent variable. There are three columns of the regression variables coefficients and the t-statistics to check the significance of the independent variable and the third column is p-value. The first term is y-intercept and the value is 3.453 and its p-value is 0.002 it means there is significant relationship between y-intercept and dependent variable. Consequences of the research composed and offered in the arrangement of a proposal. Promote appropriate sugar beet pricing system to ensure recovery of at least running and capital cost. Government should give subsidy to ensure a favorable return on sugar beet crop. Promote awareness about sugar beet crop among growers.

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INTRODUCTION

Agriculture is among the main sectors of the country's economy. The sector greatly contributes to the GDP of the country. In the current estimation carried out by the Government of Pakistan (GOP, 2025), the agriculture sector is projected to contribute 18.9% to the GDP. In addition to the generation of food and raw materials, the sector is also responsible for foreign exchange earnings and the growth of other related sectors. Despite the different challenges faced by the sector, the agriculture sector's growth rate is highly positive. The sector is also responsible for the employment of 42% of the country's working forcesIn 2024/25, the expected rate of agriculture sector growth is 3.81% (GOP, 2025). The actual output or produce potential outlook shows a large difference between actual and potential outputs. The cause for this can be attributed to a lack of technology, misuse of inputs, water scarcity, extension services, as well as a lack of education (Rehman et al., 2015). Pakistan is a gift of God. It has four seasons in a year. We possess a famous irrigation system, quality soil, and water. 90 percent of the peasants are small peasants possessing less than 12.5 acre land.

The agricultural sector is known to contribute a vast array of raw materials to different areas of the economy, and as a consequence, it has a crucial role to play in economic development. The sector acts as a backbone of a vast array of agricultural industries like food, textile, and livestock sectors (GOP, 2025). Agriculture is a major engine of economic activity that has made a significant contribution to food security, employment, and rural livelihoods of Pakistan. Estimated total production of key and secondary agricultural crops surpasses 120 million tonnes every year, thus depicting the significant production potential of the agricultural sector. Pakistan is also a prominent fruit and vegetable-producing country with annual production of more than 12 million tonnes. Production of fruits alone contributes about 7 million tonnes per annum, signifying the contribution of this sector to the agricultural economy. The relevant data signifies the significant contribution of the agricultural sector to the overall production of the country.

The agriculture sector is an important sector in the Pakistani economy. It contributes around 18.9 percent to the GDP and provides employment to almost 42 percent of the country's total working population. Moreover, besides helping meet the country's food security needs, it provides foreign exchange value to the country and provides raw materials to a number of agro-based industries, thereby helping other sectors grow. However, despite facing all these challenges, the agricultural sector in Pakistan has remained pretty much stable and is forecasted to grow by about 3.81 percent in 2024-25 (GOP, 2025). There is a wide gap between actual and potential output of the produce. This gap is due to the absence of technology, improper use of inputs, water shortage, poor extension services and lack of education among farmers (Rehman et al., 2015). Pakistan is a gift of God. It is blessed with four seasons a year. We have a well-known irrigation system, good quality soil and water. 90 percent of the farmers are small farmers owning less than 12.5 acre land.

Sugar beet is considered one of the most significant sources of sugar worldwide and also makes up a substantial portion of the world's sugar production. According to recent projections, sugar beet stands at around 20-25 percent of the total world sugar production, with the rest getting derived from sugarcane. Apart from the production of sugar, sugar beet is increasingly used as a source for the production of bioethanol. This practice is particularly prominent in Europe because sugar beet makes for a quite efficient source of bioethanol owing to the higher sugar content it has (Marzo et al., 2019; Ćirić et al., 2024).

The beets' color varies greatly, with some being white or yellowish while others are deep red; some even come with concentric rings of red and white. The red variants are generally more preferable than the white ones in food due to the higher juice content and medicinal properties they possess (Santek et al., 2010; Clifford et al., 2015). Storage roots of beet plant can be varied in shape, which can be elongated, flat, or rounded. The earthy aroma of beetroot, also described as barny or musty, is mainly attributed to the presence of geosmin and 2-methoxy-3-sec-butyl-pyrazine. These two substances have already been identified as present in a large number in beetroot, which are major contributors to its earthy aroma (Lu et al., 2003; Casciano et al., 2022).

Sugar beet has 75% water content and hence 25% dry matter. Dry matter is divided into almost 5% sugar beet pulp, known as fiber, and 75% sugar. Sugar beet pulp is produced by sugar industry and is lignocellulosic material. It is mainly used as animal feed but nowadays it is being used for preparing various foods as well as various drugs as it is rich in fiber content. It contains 70% total dietary fiber with 1/3 part as soluble and 2/3 part as insoluble fiber (Filipovic et al., 2007). Sugar beet pulp basically consists of 75-80% polysaccharides; on dry weight basis, it contains 22-24% cellulose, 30% hemicellulose, 15-25% pectin, and a minimum of 5.9% lignin, as mentioned in the paper by Yinggang et al. (2013).

The constituents of sugar beet fiber are cellulose, hemiceluloses, pectin, and lignin. Hemiceluloses and pectin give L-arabinose because of microbial fermentation in the intestines. L-arabinose is monosachride, and its sweetness is less by half compared with sucrose, thus supporting the management of hyperglycemia because of its effects on the resistance of insulin index (Autrey et al., 2017). Further, Arabino-oligosaccharides produced as a result of bacterial fermentation of sugar beet fiber by the colon bacteria may also serve as potential prebiotics. In addition, sugar beet fiber also contains acetic acid as a major short chain fatty acid produced as a result of microflora of the human colon, which acts as a buffer for stomach contents (Al-Tamimi et al., 2006).

It contains a concentration of 114-297mg/100g betaine. Its discovery started in sugar beet. This is a compound that can be produced in the human system. It aids in resisting heart, renal, and liver disorders. This ingredient in addition to folic, B12, and B6 vitamins works to lower an elevated level of homocysteine in a human being (Chidoko & Chimwai. 2011). It is superior to sugarcane in many aspects as it is a short duration (5-6 months) crop and sugarcane is a long duration (12-1`4 months) crop. Sucrose contents in sugar beet are higher as 14-20% and 1-12% in sugarcane (Arya et al., 2013). The major producers of sugar beet crop in the world include Poland, USA, Turkey, Germany, Ukraine, Italy, France and China Average yield of sugar beet is 50-60 tons ha¬-1 in many parts of the world (Bhardwaj & Singh, 2013).

Sugar Beet is generally, classified as a temperate crop but due to the development of new strains, which are resistant to the diseases, it has emerged as a prospective cash crop for the tropics and subtropics (Cosyn et al., 2011). Sugarcane has a high delta value. Hence, its cultivation is being reduced in South Africa and other tropics as well as subtropics (Chakauya et al., 2009). The demand for the water and fertilizer requirement of the sugar beet crop is 30-40% lower, as compared to sugarcane and environments with equal sucrose percentage as sugarcane (Jamal & Bahadar, 1988; Ahmad et al., 2010). Average beet weight of tropical sugar beet is between 1 to 2 kg and sucrose is 15 to 20%. Genotypic variations and agro-climatic conditions play a very important role in beet sugar contents. Mostly sugar beet is cultivated on commercial basis in temperate regions. The main producer of sugar beet crop in the world are France, USA, Germany, Russian Federation, Turkey, Ukraine, Poland, Italy and. Various experiments have been performed for the management of nutrients and adaptability of sugar beet in Peshawar valley and other areas of Pakistan (Chhapra et al.,2010; Cosyn et al., 2011).

Among the leading producers of sugar globally, Pakistan ranks as one of the top producers. On the other hand, the sugar industry in the country proves to be the second-largest agro-based sector (Iqbal & Saleem, 2015; Khan, 2024). Sugar in the form of saccharose is obtained from two different crops. These two plants are sugarcane (*Saccharum* *spp*.) and Sugar beet (*Beta vulgaris*). Further, the sugar industry in the country relies on sugarcane as its raw material. Although it is a dominant crop in the world, its production capacity of sugarcane is not in proportion to the increase in the level of demand in the country because of its water intensification, longer duration, lower productivities, and land competitiveness for foodgrain crop cultivation (Majeed et al., 2016).

Hence, the need for an alternate crop for sustainable sugar production has been increasing rapidly. Among the alternate crops to sugarcane that have been proposed for sugar production, sugar beet has appeared to be the most appropriate one with less growth time (5-6 months) and less water requirements; that is why it has been proposed as the alternate to sugarcane (Iqbal & Saleem, 2015; Tayyab et al., 2023). On a worldwide basis, sugar beet production accounts for 20-30% of the total sugar production. This indicates the important role played by sugar beet as a sugar crop. Sugar beet production as the alternate sugar crop would satisfy the sugar requirements of the world (Majeed et al., 2016). In Pakistan, sugar beets have largely been grown in the province of Khyber Pakhtunkhwa (KPK). Trials carried out in the districts of Bannu, Dera Ismail Khan, and Kohat revealed marked variation among different varieties of sugar beets regarding the production of roots and sugar percentage (Jamal & Bahadar, 1988; Khan et al., 2024). Jamal & Bahadar (1988) found that the variety Kave poly yielded the highest production of beets, while the highest sugar percentage was recorded in variety Kave-terma, suited to the agri-climatic requirements of district Bannu, KPK.

Sugar beet can easily grow in tropical as well as subtropical regions if appropriate temperatures and agricultural practices can be ensured. In sugar beet for optimal seed germination, the soil should have temperatures of 5-10°C. However, moderate temperatures help in the growth of the vegetation. Higher temperatures result in higher leaf development rather than root development. In sugar beet, optimal temperatures for growth include 25°C during the daytime and 20°C at night. However, sugar beet can tolerate temperatures of 35°C with negligible reduction in yield (Tayyab et al., 2023).

Most of Pakistani soils are alkaline, calcareous and having low organic matter (less than 1%) causing deficiencies of macro and micronutrients. In National Agriculture Research Center (NARC), Islamabad, some exotic varieties are being tested, so that can be adopted in wide range areas of Pakistan. Due to shortage of water it is the need of time that we should cultivate such crops which require less water. Similarly for fodder beet, experiments are conducted in salt affected areas of the country (Nazir et al., 2013; Erciyes et al., 2016). Sugar beet is a new crop in Bangladesh where farmers are growing this as a vegetable crop (Sanghera et al., 2016).

Sugar beet has come into the limelight as a substitute for sugarcane in the Pakistani context because of its quicker growth cycle and low water requirement. Nonetheless, despite the advantageous nature of this crop, little has been done to address the production concerns and cost viability associated with the production of sugar beets. Generally, the majority of farmers have little information regarding the cost viability and profitability associated with the production of this crop. The issue of little information has hindered the widespread use of this crop. Consequently, the cost of production and factors that affect the production of this crop, along with recommendations derived from the analysis, would be the focus of this study.

METHODOLOGY

This chapter describes various techniques and procedures which were employed in the study. These techniques were employed necessarily for research design, data collection, explaining theoretical structure, analysis of data and interpretation of the results. The study was designed to economic analysis of sugar beet and the analysis of constraints faced by them. The study was based on primary data. Simple random sampling techniques were used to collect the information through well-structured questionnaires.

Research Design

Research design refers to all those methods and measures which are employed for the collection and analysis of data. This unit describes the procedure and criteria of selection of study area and the selection of respondents used in study.

Study Area

Study area is a geography for which the data is analyzed. This study was not confined to any particular region but whole country was selected because first objective was to analyze cost of production per acre.

Data Collection

Collection of data employs different techniques to record the responses of respondents. These include qualitative and quantitative techniques like interviews, focus group discussions, surveys, etc.

Descriptive Statistics

Here, technique of the study used different basic factors as frequencies, percentages and averages relating to intermediaries. Averages were calculated by the help of the formula:

$$AM = \frac{\sum Xi}{Ni} \quad (1)$$

Where,

"AM" is arithmetic mean which is ratio sum of all the values of that variable to the sample size of individual variable (Antonio and Joaquim, 2008). "$\sum X_i$" is sum of all values of the individual variable and "N_i" is its number of observations.

For making comparisons and considerations, percentage (P) was calculated with the help of following formula:

$$P = \frac{F}{N} \quad (2)$$

Where,

F= Frequency of a class and N= total number of observations. Percentage is calculated to be ratio of two variables, in our case, frequency of a class to its total observance, multiplied with 100 to properly describe in terms of percentage (Antonio and Joaquim, 2008).

Economic Analysis

Economic analysis of the intermediaries involved in the sugar beet value chain was performed through their analysis of marketing margins:

For analysis of the marketing margin of intermediaries, following techniques were used:

Gross Margin

Gross margin was calculated for the purpose of making comparison between intermediaries. It is the difference of two variables normally earnings and cost and in our study it is mentioned as under:

$$\text{Gross Margin (GM)} = \text{Total Revenue (TR)} - \text{Variable Cost (VC)} \quad (3)$$

Where, total revenue (TR) refers to the revenue received by selling the sugar beet product and variable cost (VC) is the price paid for buying those products

RESULT AND DISCUSSION

This section will report and interpret the results of the analysis of the primary data that have been collected in this study. These results are presented in relation to the identified study objectives, and necessary descriptive, analytical, and economic tools are used to interpret them. These results will not only give an insight regarding the cost structure, profitability, and challenges of sugar beet production, but at the same time will identify the performance level of the middlemen engaged in this sector in terms of the identified value chain. Whenever necessary, this section will use the previous studies and will establish similarities and contrasts so that the results of this research study are presented in a larger context. The discussion section further correlates the empirical findings to the theoretical framework on which the study is based and establishes implications for farmers and policymakers.

Table 1: Socio-Economic Characteristics of the Respondents (n = 100)

Variable	Category	Frequency	Percent
Age (years)	25–30	20	20
	31–35	29	29
	36–40	38	38
	41 and above	13	13
Education	Primary	12	12
	Secondary	24	24
	Matric	20	20
	FA	19	19
	B.A	17	17
	M.A and above	8	8
Farming Experience (years)	5–10	12	12
	11–15	31	31

	16–20	45	45
	21 and above	12	12
Family Size	1–2	25	25
	3–4	41	41
	5 and above	34	34
Family Members Working on Farm	Full time	38	38
	Part time	62	62
Labor Type	Permanent	44	44
	Daily wages	56	56
Income Source	Farming	20	20
	Govt. employee	22	22
	Own business	16	16
	Private job	21	21
	Retired govt. employee	14	14
	Others	7	7
Total Monthly Income (PKR)	10,000–15,000	18	18
	16,000–20,000	30	30
	21,000–25,000	39	39
	26,000 and above	13	13
Wage Rate of Labor (PKR)	10,000–15,000	16	16
	16,000–20,000	44	44
	21,000 and above	40	40

Table 1 represents the socio-economic profiles of the respondents enrolled in the study. Around 38% of the respondents belonged to the age group of 36 to 40 years, and the second highest (29%) belonged to the age group of 31 to 35 years. In terms of education, it was observed that the highest number of respondents (24%) possessed education between Secondary to Bachelors' level. Around 20% of the respondents possessed a Matric pass qualification, and only 8% held a Master's degree or above.

Concerning agricultural experience, a large percentage (45%) of the respondents revealed that they had 16-20 years of experience in agriculture; hence, it can be deduced that the agricultural community was quite experienced in agriculture. Regarding analysis of the size of the families of the respondents, it was revealed that 41% of the respondents' families consisted of 3-4 people, and 34% belonged to families that consisted of at least five individuals. Concerning labor participation, 62% of family members participated in farming on a part-time basis, while 38% participated on a full-time basis. Additionally, 56% of the respondents hired labor on a daily wage basis, while 44% hired permanent labor.

Income sources analysis shows that the respondents were involved in different sources such as government jobs with 22%, agricultural jobs with 20%, private jobs with 21%, and self-owned businesses with 16%. In monthly household income, it has been observed that 39% of respondents possess income between PKR 21,000 to 25,000, followed by 30% who possess income between PKR 16,000 to 20,000. In labor wage sources, 44% of respondents pay wage between PKR 16,000 to 20,000, followed by 40% who pay wages beyond PKR 21,000. The table provides an outlook on the diversified socio-economic background of the respondents involved in this research.

Table 2: Distribution of Agricultural Landholding and Operational Area of the Respondents (n = 100)

Variable	Land Size (Acres)	Frequency	Percent
Owned Area	1–2	21	21

	3–4	41	41
	5–6	38	38
Rented-in Area	1–2	19	19
	3–4	37	37
	5–6	44	44
Rented-out Area	1–2	28	28
	3–4	32	32
	5–6	40	40
Shared-in Area	1–2	20	20
	3–4	40	40
	5–6	40	40
Operational Holding	1–2	19	19
	3–4	39	39
	5–6	42	42
Farm Size	1–2	10	10
	3–4	27	27
	5–6	47	47
	7 and above	16	16

The Table 2 showcases the distribution of respondents in regard to various dimensions of agricultural landholding. The dimensions covered include the owned land area, the rented in land area, the rented out land area, the shared in land area, operating holding, and the total size of the farm. As for the land they own, 41% of respondents own 3-4 acres of land, and 38% own 5-6 acres of land. As for the land they rent-in, 44% of respondents cultivate 5-6 acres of land. Similarly, rented-out land was more common for respondents with 5–6 acres of land, at 40%, reflecting land adjustment practices based on resource availability.

Presently, shared-in landholding is equally distributed between the 3–4 acre and 5–6-acre categories, with each category obtaining 40% of respondents. However, an analysis in operational holding indicated that 42% of respondents operated 5–6 acres of land, which was followed by 39% operating 3–4 acres. Lastly, farm size distribution had almost half of the respondents, at about 47%, having farms ranging between 5–6 acres, while 16% operated farms of 7 acres or above.

It is important to note that the table above indicates that the majority of the respondents have medium-scale farms. The farms have land that is owned, rented, and shared with the aim of maximizing agricultural production. This has a significant impact on agricultural production. The size and scope of the land have a substantial impact on the economic viability of the production of sugar beets.

Table 3: Farm Location Characteristics and Soil Conditions of the Respondents (n = 100)

Variable	Category	Frequency	Percent
Distance from Main Road	0.5 km	10	10
	1.0 km	26	26
	1.5 km	45	45
	2.0 km and above	19	19
Distance from Main Market	0.5 km	12	12
	1.0 km	25	25
	1.5 km	43	43

	2.0 km and above	20	20
Soil Type	Sandy	25	25
	Loam	38	38
	Clay	37	37
Soil Fertility Level	Low	27	27
	Medium	35	35
	High	38	38
Soil Salinity Level	Low	20	20
	Medium	41	41
	High	39	39
Soil Testing Practice	Yes	72	72
	No	28	28

The distribution of respondents by characteristics of farmland location and soil conditions is outlined in Table 3. From the results, the majority of the farm locations are found to be at a moderate distance from the main road and main market. A total of 45% of the respondents perceived the distance of the farmland location to be about 1.5 km from the main road, while 43% perceived a similar distance of about 1.5 km from the main market.

In soil type, loamy soil was the most dominant soil type, contributing 38%, followed by clay soil with 37%, while sandy soil was the least, contributing 25%. In soil fertility, more of the respondents, contributing 38%, said that soil fertility is of a higher magnitude, while 35% said medium, while 27% said low soil fertility. The result of soil salinity shows that medium soil salinity, contributing 41%, followed by high salinity soil, contributing 39%, would not favor crop production.

The table further shows that the majority of the respondents, 72% of them, practiced soil testing, indicating that they were aware of the soil health and nutrient management, while 28% did not practice soil testing. In sum, these findings confirm that farm location and soil conditions determine agricultural productivity and efficiency of production, particularly in sugar beet production.

Table 4: Production Outcomes and Farm Management Practices of the Respondents (n = 100)

Variable	Category	Frequency	Percent
Crop Performance After Sowing	Good	19	19
	Normal	41	41
	Below Average	40	40
Irrigation System Used	Canal	60	60
	Tube Well	40	40
Type of Spray Used	Generic	48	48
	Branded	52	52
Harvesting Method	Manual	7	7
	Reaper	39	39
	Combine Harvester	54	54
Threshing Method	Manual	9	9
	Reaper	46	46
	Combine Harvester	45	45
Yield per Acre (Maunds)	500	16	16

	501–1000	24	24
	1001–1500	41	41
	1501–2000	19	19

Table 4 above shows the results of production and farm management approaches used by the respondents. Regarding crop performance after planting, 41% of the respondents got normal performance outcomes, 19% experienced good performance, and 40% performed below average.

Concerning irrigation management, canal irrigation was the commonly practiced irrigation method, with 60% of the respondents using this technology, while 40% used tube wells, indicating a mixed level of usage of groundwater and surface water resources. Turning to crop protection, a slight higher percentage of the farming population (52%) utilized branded spray compared to generics (48%), indicating a medium level of usage of improved technology for this purpose.

The levels of mechanization differed by harvesting and threshing methods. The dominant method of harvesting using mechanized equipment was by combine harvesters (54%), followed by reapers (39%), while the least method of harvesting was by manual means (7%). The method of threshing using mechanized equipment was dominated by reapers (46%) and combine harvesters (45%), while the least method of threshing was by manual means (9%).

The yield per acre distribution shows that the largest number of respondents (41%) produced crops between 1001 and 1500 maunds per acre, followed by 24% with crop yields between 501 and 1000 maunds. A few farmers (19%) produced more: between 1501 and 2000 maunds, whereas 16% produced around 500 maunds per acre. The table indicates that there was quite an element of variation in crop production.

Table 5: Marketing, Irrigation, Credit Access, and Institutional Characteristics of the Respondents (n = 100)

Variable	Category	Frequency	Percent
Sold in Market	Yes	85	85
	No	15	15
Market Price (Rs.)	1000–2000	10	10
	2001–3000	45	45
	3001 and above	45	45
Source of Irrigation	Canal	18	18
	Tube well	47	47
	Canal + Tube well	35	35
Type of Tube Well	Electric	20	20
	Tractor operated	27	27
	Peter engine	36	36
	Turbine	17	17
Power of Tube Well Motor (HP)	20	20	20
	21–25	26	26
	26–30	36	36
	30 and above	18	18
Time Required to Irrigate (per acre)	1–2 hours	16	16
	3–4 hours	23	23
	4–5 hours	42	42
	5 and above	19	19
Rate of Tube Well Water (Rs.)	500–1000	20	20

	1001–1500	26	26
	1501–2000	36	36
	2000 and above	18	18
Rate of Canal Water (Rs.)	500–1000	20	20
	1001–1500	24	24
	1501–2000	38	38
	2000 and above	18	18
Weight Measurement Method	Satisfactory	31	31
	Unsatisfactory	69	69
Mode of Sale	Village beopari	7	7
	Commission agent	48	48
	Processing unit	45	45
Number of Buyers	Single	9	9
	Few	51	51
	Many	40	40
Commission Fees	Large	50	50
	Small	50	50
Mode of Payment	On spot	14	14
	At due date	49	49
	Delayed	37	37
Credit Facility Availed	Yes	41	41
	No	59	59
Amount of Credit (Rs.)	5000–10000	18	18
	10001–15000	26	26
	15001–20000	38	38
	20001 and above	18	18
Amount Needed (Rs.)	5000–10000	20	20
	10001–15000	26	26
	15001–20000	36	36
	20001 and above	18	18
Source of Credit	ZTBL	20	20
	Commercial banks	30	30
	Relatives	19	19
	Fellow farmers	10	10
	Others	21	21
Contact with Agriculture Department	Yes	49	49
	No	51	51

Table 5 gives a detailed summary of marketing practices, irrigation arrangements, credit accessibility, and institutional connectivity of the respondents. The statistics show that 85% of the farmers marketed their produce in the market, with many getting more than Rs. 2000 per unit.

The watering system uses a large percentage in tubewells, either exclusively (47%) or in combination with canal water (35%), which shows more reliance on groundwater. The tubewells functioned using either peter engines (36%) or tractor-driven water systems (27%), with a substantial percentage using motors in the 26-30 horsepower range. The irrigation time per acre had high values, with 42% of the farmers needing 4-5 hours per acre.

Water price addition will also add to the cost of production, as canal and tube wells irrigation charges ranged between Rs. 1501-2000. There will be inefficiency in the marketing process, as 69% respondents showed dissatisfaction in the measurement of weights, and almost half sold through commission agents or processing units. There will be delay in getting payments, as only 14% received on the spot payments.

The credit constraint is still limited, as only 41% of the respondents utilized credit services. The majority of these users borrowed Between Rs. 15001 and 20000 from commercial banks and ZTBL. Lastly, the institutional outreach seems limited, as more than half of the respondents had no contacts with the agriculture department. The above table shows the importance of limitations in irrigation dependence, market structure, credit, and institutional constraints to farm profitability.

Table 6: Cost of Crop Management Practices of Sugar Beet per Acre

Cost Component	Particulars	Quantity	Cost per Unit (Rs.)	Total Cost (Rs.)
Land Preparation	Raonni	1	120	120
	Deep ploughing	3	1800	5400
	Ploughing	3	1000	3000
	Laser leveling	1	1000	1000
Seed Cost	Seed rate per acre	–	9000	9000
	Seed price per kg	–	4500	4500
Labor Cost	General labor	–	1700	1700
Fertilizer Cost	Urea	3	1800	7200
	Potassium sulfate	1.5	4000	6000
Irrigation Cost	Tube well	10	120	1200
Subtotal (Crop Establishment)				39,120
Pesticides / Weedicides	Manual weeding	4	3500	14,000
	Insecticides	2	600	1200
Spray Application	Machinery spray	2	200	400
Harvesting Cost	Harvesting (all methods)	1	14,000	14,000
Subtotal (Plant Protection & Harvesting)				29,600
Total Cost of Production				68,120
Yield per Acre (Maunds)		900	–	–
Market Price (Rs./Maund)		120	–	–
Total Revenue				108,000
Net Profit				39,880

The cost structure per acre in sugar beet cultivation, which includes costs related to land preparation, seeds, labor, fertilizers, water, plant protection, and harvesting, is shown in Table 6. It was estimated that the total cost of crop management per acre would be Rs. 68,120.

The cost of land preparation was a significant component of overall expenses, primarily due to deep plowing and multiple plowing. The use of seeds and fertilizers was also a significant component of production expenses, primarily due to the input-intensive nature of sugar beet production. Amongst the fertilizer nutrients, urea and potasssium sulfate were the key contributing factors.

The activities related to crop protection and harvesting also significantly increased the overall cost. In the subtotal for pesticides, weedicides, and harvesting, the cost of Rs. 29,600 per acre accentuates the significance of human resources and machinery needed for crop management.

The average yield of 900 maunds of sugar beets was obtained per acre at a market price of Rs. 120 per maund, thus realizing a total of Re. 108,000 per acre. The net profit realized from sugar beet production, after subtracting the total cost of production, was estimated at Re. 39,880 per acre. The results obtained here establish that sugar beet production is a profitable venture, though increasing production and labor costs could impact this profit margin negatively.

Table 7: Regression Analysis of Cost Components Affecting Sugar Beet Production

Model Variable	Coefficient	t-Statistic	p-Value
Constant	3.453	5.22	0.002
Land preparation	1.32	3.67	0.003
Raonni	3.53	3.94	0.012
Deep ploughing	4.22	2.42	0.005
Ploughing	4.82	2.04	0.011
Planking	2.11	12.42	0.000
Laser leveling	0.42	8.44	0.010
Seed rate per acre	3.22	3.65	0.034
Seed price per kg	10.32	5.02	0.020
Seed treatment cost	5.33	7.47	0.010
Labor cost	3.98	3.75	0.120
Fertilizer	2.67	2.94	0.134
Urea	1.54	6.30	0.023
DAP	4.77	11.43	0.002
Potassium sulfate	2.76	20.40	0.000
FYM (Trolleys)	2.90	3.54	0.056
Others	2.89	7.44	0.024
Labor cost (additional)	1.90	3.64	0.046
Irrigation	2.49	3.09	0.067

Dependent variable: Sugar beet production cost/output (as specified in the model).

The Table 7 indicates the result of multiple linear regression model. The multiple linear regression method can be applied when the number of independent variables is more than two, and one dependent variable. The result of multiple linear regression method includes three columns of regression variables' coefficients to find the significance of the independent variables, and the third column indicates p-values. The first column refers to the y -intercept value, which is 3.453, with a p-value of 0.002, indicating a significant relationship between y -intercept and dependent variables.

The first variable is Land preparation and its coefficient is 1.32. It means if we raise one unit in Land preparation then 1.32 will be increased in Production. Moreover, the p-value of the land preparation is less than 0.05 it means there is significance relationship between the production and land preparation. Next is Raonni and its coefficient is 3.532. It means if we raise one unit in Raonni then 3.532 will be decreased in Production. Moreover, the p-value of the Raonni is less than 0.05 it means there is significance relationship between the production and Raonni. The next variable is deep ploughing and the coefficients of Deep ploughing is 4.22. It means if we enhance one unit in Deep ploughing then 4.22 will be enhanced in Production. And the p-value of the deep ploughing is less than 0.05 it means showing significance relationship between production and deep ploughing. The next variable is Ploughing and the coefficients of Ploughing is 4.82. It means if we enhance one unit in Ploughing then 4.82 will be enhanced in Production. And the p-value of the Ploughing is less than 0.05 it means showing significance relationship between production and Ploughing. The next variable is Planking and the coefficients are 2.11. It indicates that if one-unit changes in ploughing then 2.11 will change in Production. And the probabilities or the p-value of the Planking is less than 0.05 it indicates that significance relation exists in the production and Planking.

The next variable entered into the model is Laser leveling and its coefficient values to the model are 0.42. This implies that as the increase in the one unit of the value for the Variable "Laser leveling", the value for "Production" will increase by 0.42. The p- value for the "Laser leveling" is less than the significance level of 0.05. This implies that the "Production" and "Laser leveling" have a significance relationship. The next variable is Seed rate per acre and its coefficients is 3.22. it means if we increase one unit in Seed rate per acre then 3.22 will be increase in Production and the p-value of the Seed rate per acre is less not than 0.05 it means there is no significance relationship between the production and Seed rate per acre. The next variable is Seed price per kg and its coefficients is 10.32. It means if we increase one unit in Seed price per kg then 10.32 will be increase in Production and the p-value of the Seed price per kg is less than 0.05 it means there is significance relationship between the production and Seed price per kg.

The next variable is Seed treatment cost and its coefficients are 5.33. It means if we increase one unit in Seed treatment cost than 5.33 will be increase in Production and the p-value of the Seed treatment cost is less than 0.05 it means there is significance relationship between the production and Seed treatment cost.

The next variable is the Labor cost, whose coefficient is 3.98. It means that if one unit is increased in the Labor cost, then the value of 3.98 will be increased in the Production. And the p-value of the Labor cost is less than 0.05, which means that there is no significance relation between production and Labor cost.

The next variable is Fertilizer, with coefficients of 2.67. That means that if we increase one unit in Fertilizers, then 2.67 will increase in Production. Its p-value is also less than 0.05, meaning that there will be no significant relationship between the production and Fertilizers.

Generally speaking, the regression results confirm that land preparation, quality of seed input, and proper application of fertilizers in balanced rates all form the basic ingredients of sugar beet production performance.

Discussion

Regression results in Table 7 are rather informative regarding the factors influencing the production of sugar beet, emphasizing the significance of land preparation, seed, fertilizer, and irrigation factors. The overall test for the significance of the equation bears out the fact that production outcomes are influenced by management practices rather than random factors, which is in line with what would be expected in production theory of agriculture.

Variables of land preparation have a strong and significant relationship with sugar beet production. Raonni, deep ploughing, ploughing, planking, and laser leveling have all positively and significantly affected the dependent variable. A positive sign indicates that a superior land preparation practice increases the performance of the crop. These findings are in agreement with recent studies that show proper tillage enhances soil structure, improves moisture retention, and root penetration, which become particularly crucial for root crops like sugar beet (Bian et al., 2016; Oshunsanya et al., 2018; Gorski et al., 2022). Laser leveling, though having a relatively small coefficient, remains statistically significant, supporting evidence that precision land leveling leads to even water distribution and improved crop productivity (Tomar et al., 2020).

Variables related to seed influence the final production. The positive and significant influence of seed price per kilo indicates that more expensive and presumably high-quality seed types are major contributors to increased production. This supports recent agronomic analysis that certified and hybrid seed types are more effective in terms of increased germination capacity, improved seed vigor, and improved sugar content in sugar beet (Aly and Khalil, 2017; Mahmoud et al., 2018; Mall et al., 2021). Additionally, seed treatment cost has significant influence, which indicates its significance in seed protection strategies against soil-borne diseases and early pest infestations, as confirmed by (Lamichhane et al., 2022). However, the seeds per acre on the other hand do not have a significance regarding production. This implies that above a certain optimal level, the higher the seeds, the less the effect on production. This study fits well with the study by Ahmad et al. (2017), which postulates that high seeds rates may be responsible for intra-plant competition, which can neutralize the increase in production.

Fertilizer use presents an indeterminate situation. Although total fertilizer use is not significant, individual components like urea, DAP, and potassium sulfate have a positive and significant influence on production. This highlights the significance of a proper use pattern of these components rather than the total use of fertilizers. Findings from recent studies on sugar beets reinforce these conclusions, which stress the vital roles of nitrogen, phosphorus, and potassium in a complementary manner in root development and sugar formation (Mahapatra et al., 2020; Kaliyeva et al., 2024).

The marginal significance of farmyard manure (FYM) indicates that organic matter has a positive contribution, but it takes some time to show significant results. Labor cost and irrigation are positively but statistically insignificant in relation to production. This indicates that even though labor and water are vital resources, efficiency in use rather than use alone matters. The studies done in South Asia found that marginal returns in labor and irrigation are decreasing in case of inefficient management practices or misallocation in use (Muzammil et al., 2020; Raza et al., 2021).

In the end, the results confirm the efficacy of land preparation, seed, and fertilizer as the most paramount input in the determination of the level of sugar beet output. The results have various implications in the context of formulating policies. For instance, based on the results, training of the farmer in land preparation approaches ought to be the top area of concern in the extension program.

CONCLUSIONS

This research focused on economic efficiency of sugar beet farming and made an assessment of agricultural practices of sugar beet production, cost structure, and its impact on sugar beet yield based on primary data and regression analysis. The study clearly shows that sugar beet farming is an economic activity, which has positive net returns per acre, but it is highly sensitive to management of inputs and agricultural practices. The results of the regression analysis indicate that land preparation practices like raonni, deep, and shallow ploughing, as well as planking and laser leveling, strongly contribute to an increase in sugar beet yields. This is because these practices influence soil qualities like structure, water retention capacity, and root development, which are core in ensuring that sugar beet performs well. Seed variables, like quality and treatments, also highly influence sugar beet yields. The use of fertilizer establishes that the use of fertilizer nutrients, particularly nitrogen, phosphorus, and potassium, is more important than the use of fertilizer. While the use of labor and water in production is vital, the effect of these factors on output seems to rely on efficiency rather than cost intensity. The study also indicates that mechanization, access to quality inputs, and sound management practices have the ability to shape production. Overall, the study confirms that more efficient agronomic practices, combined with more efficient use of inputs and better access to technical knowledge, result in productivity gains in sugar beet cultivation. The removal of inefficiencies in production and marketing systems could significantly improve farm profitability and contribute toward the sustainability of sugar beet farming.

Policy Recommendations

Based on the empirical findings of the study, the following policy recommendations are proposed:

Promotion of Improved Land Preparation Practices: The agricultural extension agencies should focus on the use of appropriate land preparation methods such as intensive ploughing, planking, and laser land leveling. Subsidized or joint costing for laser land leveling would help small to medium-sized farm operators improve land levelness and water management practices.

Enhancing Access to Quality Seed and Seed Treatment: Policymakers should ensure the availability of certified and high-quality sugar beet seed at affordable prices. Public–private partnerships can be encouraged to strengthen seed supply chains, while extension programs should promote seed treatment practices to reduce early-stage crop losses.

Balanced Fertilizer Management through Soil Testing: The research emphasizes the need for balanced application of fertilizer. Government institutions need to extend the facilities involved in soil testing as well as promote the application of fertilizer depending on the nutrient status. Benefits for balanced nutrient management can further boost production by eliminating unnecessary costs.

Improving Irrigation Efficiency and Energy Use: Owing to the dependence on tube well irrigation, there should be a focus on the promotion of energy-saving irrigation methods, as well as conjunctive use of canals and groundwater. There is a need to introduce water-saving irrigation technologies that will help lower production costs.

Strengthening Agricultural Extension and Farmer Training: Training programs need to be conducted regularly to inform the farmers about the latest advances in agronomy practices, labor management, and the possibilities of mechanization. Enhancing the interaction between the farmers and the agriculture extension departments would help.

Market and Institutional Support: In an attempt to enhance earnings for farmers, an element of reform in terms of the markets and payment systems, as well as proper weighing of products, has been recommended as a means of enhancing efficiency. Extending credit to the farmers and making it favorable would also contribute significantly.

Support for Mechanization and Cost Reduction: The promotion of mechanized harvest and threshing practices may help cut labor costs and post-harvest losses. Economic incentives and credit facilities for the use of farm machinery may help improve efficiency and minimize production risk.

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