Yield maximization and Adaptation of Optimal Cropping Pattern; Option for Gilgit Valley in GB

Dr. Arshad Mahmood Malik (Corresponding Author)
Department of Economics and Agriculture-Economics,
PMAS Arid Agriculture University, Rawalpindi, Pakistan
Email: arshadmm@uaar.edu.pk

Sania Zahra (Corresponding Author)
Department of Economics and Agriculture-Economics,
PMAS Arid Agriculture University, Rawalpindi, Pakistan
Email: zahrasania903@gmail.com

Abstract

Choosing the right crops to grow in a certain agricultural region has been a long standing and mostly an empirical challenge for food security. The assessment of the potential and suitability of agricultural crops for present and the future food production requires the evaluation using analytical and optimization approaches. Food security and rural development depends on the suitable growth of the agricultural industry. The main objectives of the study were to develop linear programming model through the General Algebraic Modeling System (GAMS) program for assessing the optimally crops yield, which would lead to optimal cropping pattern, maximize income from crop production and explore investment opportunities through analyzing the effects of additional capital on cropping yield and income of the farmers. The study was carried out in the district Gilgit. Linear Programming Model was applied to calculate the crop acreage, production and income of the crops. Crops included in the model were wheat and potato. The growers of the major crops were the targeted population and random sampling technique is used to select the sample. Two stage sampling techniques are applied for collecting data. In the first stage the farmers of the study area are divided into two groups; the potato growers and the wheat growers and in the second stage randomly 100 farmers (50 farmers from each group) are interviewed for the study and questionnaires are filled on the spot. Self-made questionnaires, filled through interviewed process from the random selected farmers were used as a tool for collecting primary data. The raw data is tabulated and analyzed using Microsoft Excel. The analyzed data is used to develop the mathematical model. Simplex method is applied to find the optimal solution of the model, which showed 11% increase in the net revenue per year. LP is a superior and suitable model for use in any decision making situation because of its highly appreciated results. So it is strongly recommended for putting the suggestions of linear programming model into practice in their daily life to get maximum advantage from available resource with lowest expenses.

Keywords: GAMS modelling, Linear Programming, Optimal Solution, cropping yield, Cropping pattern.
JEL: D24, C61

Introduction:

The magnitude of the agriculture market has increased dramatically within recent era. It is anticipated to increase from dollar 13.27 trillion to dollar 14.35 trillion in 2024 at an 8.2 percent compound increase yearly expansion rate. The historical periods rise can be ascribed to various sources, including population expansion trade globalization, governmental policies, crop product use, and the impact of weather patterns and climate. Furthermore, programs like rural development initiatives has been crucial in promoting the expansion of agriculture industry. (Agriculture Global Market Report 2024).

Empirical methods have traditionally been used to tackle the difficult problem of choosing the best land for agricultural crop cultivation (Everest et al., 2021). Even though a lot of governments, institutions, organizations, and researchers have worked hard to develop frameworks for the best possible use of land, a large portion of agricultural land is still not being used to its full potential. Given the growing demand for food production and resource scarcity, it is imperative to use advanced procedures of land calculation to support for making judgment in their role as managers of cultivable area as sources of greater profitability for producers (van Dijk et al., 2021). Significant benefits can be realized with little effort by giving priority to cultivating the most suitable land. Furthermore, economic evaluation is crucial because it offers a straightforward but crucial way to evaluate how economic factors influence setting up utilization of land to increase profit (Kalogirous, 2002).

Food security and rural development in Pakistan are dependent on the agriculture sector's continuous growth. It makes a substantial contribution to both employment and foreign exchange earnings for the country. Furthermore, it provides industrial raw materials, so growth in this sector has multiple positive effects on the economy as a whole (Aslam, 2016; Chandio et al., 2016). About 38 percent of the labor force finds work there as a manager of the rural landscape and environmental shield (Usman, 2016), and it also maintains and enhances the ecosystem and output that are climate-resilient (Gop, 2022).

Enhancing the economic growth of agricultural countries is largely dependent on agriculture. Making the right decision from a wide range of options is the biggest problem in the agriculture sector. For resolving such problems, linear programming is the most effective method. To address comparable circumstances, Ishtiaq et al. (2004) used the linear programming model to figure out that which crops like wheat, basmati rice, IRRI rice, cotton, sugarcane, maize, and potato would be best suited for cultivation on

the 2702,000 acres of irrigated land which make up the Faisalabad division. The best crops, based on the ideal result, were cotton, wheat, and maize, and net income increased by 2 percent.

In order find the comparative benefit of strawberry farming in NWFP's subtropical regions, Ghulam et al. (2009) applied LP. Although wheat was not included in the ideal outcome, the LP model recommended setting aside 0.6799 acres of area for strawberry yield and 2.80 acres for sugarcane yield. After accounting for 0.97 acres of unused land, the LP model raised net income from Rs. 111.861 thousand to Rs. 161.263 thousand.

Felix (2013) apply the LP model to benefit growers in Marondera and Zimbabwe, create the optimal solutions possible in the case of apportionment of distributed assets for maximization of net revenue. Results figure out that farmer net income increased by 35 percent while total crop acreage decreased by 30 percent. Good management is the single most important factor in raising agricultural productivity.

Amin et al. (2013) determine the highly efficient method to use assets in different regional cultivation carried out a research in tri Iranian nations. Then, in order to examine the procedure, they developed a linear programming model. The results of the research concluded that the optimal crop plan enhance the net-profits in Babol, Babolsar, and Qaemshahr by 6.8 percent, 8.9 percent, and 5.6 percent, respectively. The entire region's profit will rise to 1.4 percent as a result to the multi-regional model. The enhanced the land distribution had benefit for grower's income.

In order for determine best land allocations for the crops. Aquil et al. (2015) created an LP model using agriculture information for 05 different food crops. When the linear programming model compared the present results, it was found that 2752.56 acres, as opposed to 2409 acres, was the ideal amount of land used. The linear programming model yielded a maximum profit of Rs. 1376.

Ishtiaq et al. (2005) create a LP model to calculate Punjab's Dera Ghazi Khan region crops cultivation. A total of 3913 thousand acres of cropped area were studied, with crops such as wheat, cotton, sugarcane, basmati rice, and IRRI rice. The best crop is Cotton, which occupies ten percent of the total area and increase net revenue by three percent over the grower's initial plan, according to the optimal result of the LP model.

Egypt's copping pattern applying the LP model. They made use of 28 crops' five-year data from 2008 to 2012 (Sara et al., 2017). The authors find relief in the fact that the study area's net profit increased by 6.44 percent as a result of the LP results. In order to achieve sustainable agriculture and maximize profit by determining the ideal harvesting design, a fuzzy Linear Program model was created (Ziaee et al., 2014). The Linear Program outcomes indicates as in order to maximize profit; wheat should be increased. Ishtiaq et al. (2004), Felix et al. (2013), Mushtaq et al. (2014) and Shreedhar et al. (2015) are recommended reading for interested readers seeking further information.

A vital part of any region's economic development is the agriculture sector, which engages in a wide range of activities. Making decisions for the best possible activity selection is the primary challenge in agriculture. With these important considerations in mind, a research analysis which figures out in District Gilgit inorder for determining, best harvesting strategy for the two main crops grown there, potatoes and wheat, as well as to optimize annual net profit. District Gilgit offers a lot of potential for agriculture, but the cropping practices used now might not be the best for maximizing yield. There is a need to investigate the feasibility and effectiveness of adopting an optimal cropping pattern through the application of a General Algebraic Mathematical Model (GAMS). The following are the primary queries that of the research seeks for response: What cropping practice is performed in Gilgit District right now? How can the yield be maximized by optimizing these patterns? What possible effects might an ideal cropping pattern have on the region's agricultural sustainability and productivity? By exploring these questions, this study seeks to contribute the enhancement of agricultural practices and livelihoods in District Gilgit."

Subsistence farming has gradually given way to the production of fruit and cash crops; this trend is particularly noticeable in the regions that are more easily accessible and closer to cities. The growing percentage of domestic revenue gained through other than farming sources, which rose from forty-three percent in 1994 to sixty-three percent in 2005 (World Bank 2010) also over seventy percent in 2020, is another significant factor for development of the non-urban income (Shahzad et al., 2021). Similar to this, improved formal education systems have led to a rise in labor outflow into the services sector, which has raised the percentage of non-farm employment in down-country Pakistan. In 2001, about 24 percent of men (over the age of 18) had employment outside of rural GB, compared to a migration rate of 15 percent for the same group throughout rural Pakistan (World Bank 2010).

Four of GB's five districts are categorized as "extremely insecure" in terms of food security, while Gilgit is the final district and is classified as "very insecure" in a 2010 World Bank study. Farming communities in Great Britain are essentially in danger of going extinct under these circumstances. The results of growing rates of migration towards the urban areas from the rural areas (Anwar et al., 2019). Particular among youth and the quickly growing other than farming sector (Gioli et al., 2014) are decrease cultivatable area usage hence improved ambiguity about farming maintenance (Goeller, et al., 2012). Similar worries about farms' survival because of a lack of young heirs have been reported in distinct areas of world (Misra et al., 2010). One term for this phenomenon is the "inheritance dilemma" (Gasson, et al., 1998). In many places, reduced rate of farming progression which links to non-urban relocation. Rural zones, particularly underprivileged along with marginalized parts, farming plays a vital for livelihood among the people living there (Hinojosa et al., 2016). Even

though inters-generation farming progression retains important drivers of farming existence within Great Britain, recent developments call for a quick investigation of the problem. Finding out whether it was possible to identify the study region's potential farm successors, how they intended to carry on with their line of work, and what the locals thought of the situation are key objectives of the present study.

Methodology:

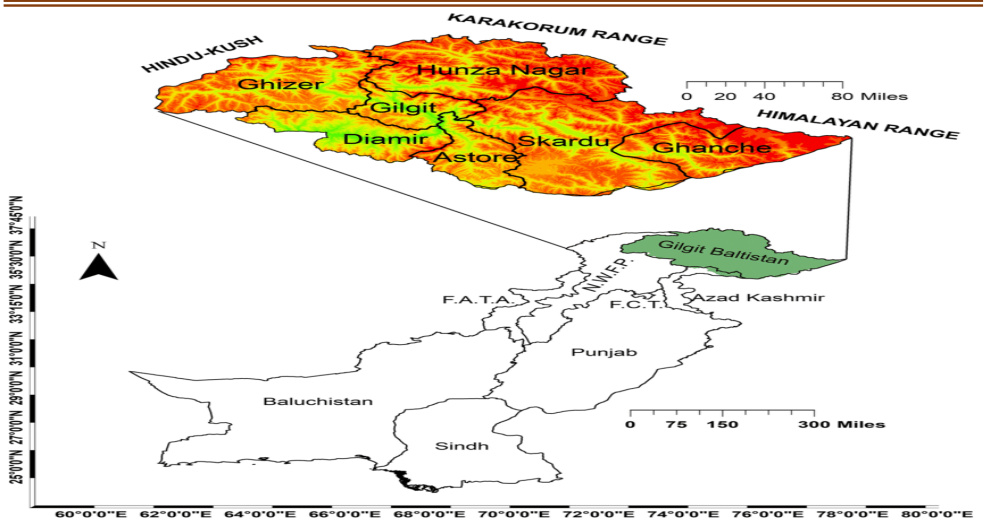
Study Area:

Government department of agriculture in Gilgit-Baltistan (2014) states that the region is located in the northern region of Pakistan. The principal food and commercial crops farmed in Gilgit-Baltistan region are potatoes, maize, and wheat. The most promising source of goods for the locals' subsistence has been shown to be these crops. In order to optimize net profit annually and investigate the most advantageous crop arrangement for two major crops grown up in the study part potato and wheat, this research study is being carried out in District Gilgit. Since the study address by numerical data and truths. Principal geographic divisions of District Gilgit are the Nomal Valley, Bagrot Valley, Juglot, Danyore, Sultanabad, and Naltar Peak. The study area spans approximately 14,672 square kilometers. There are two cropping zones, according to Gilgit-Baltistan's Directorate of Agriculture (2013). According to Table #1, cultivators should use the double cropping and single cropping zones to grow as many crops and vegetables as they can throughout time of year to fulfill their fundamental requirements. Two main crops farmed at research zone first is cash crop (potato) and the other is food crop (wheat).

Table 1: The Cropping Regions and its structure for GB.

Name of Zone	Altitude in meters	Agricultural Regions	Leading Crops
Two Crop Zone	Twelve hundred-sixteen hundred	Chilas region, Jaglot region, Gilgit region	Wheat, Maize, Barley, Vegetable, Clover
Marginal two Cropping Zone- a	Sixteen hundred-two thousand	Ghanche region, Skardu region	Wheat, Maize, Barley, Vegetable, Clover
Marginal two Cropping Zone- b	Two thousand-twenty four hundred	Karimabad region, Yasin region, Kharmang region ,	Wheat, Barley, Vegetable, Turnip, Millet
Upper Single Cropping Zone	Twenty four hundred- three thousand	Darkut region, Phandar region, Naltar region, Gultari region	Wheat, Maize, Barley, Potato

Source: Directorate of Agriculture, Gilgit-Baltistan, 2013.



Source; *https://www.researchgate.net/figure/Location-of-Gilgit-Baltistan-in-the-map-of-Pakistan-The-topography-and-the-district_fig1_330484598*

Data and Methods of Solutions:

The methodology of the study constituted the application of primary and secondary research instruments that adopted a participatory approach. The secondary data was gathered from the government department of agriculture in Gilgit-Baltistan (GB) in 2014. Statistics on agriculture. MAKNA (2009), the Government of Gilgit-Baltistan (2009) and a few other sources. On the other hand, primary information gathered in District Gilgit via in person interviews and survey questions. The targeted population involved of the growers of the major crops, and the sample was determined using a random sampling technique. Two stage probability sampling methods is applied for collection of data. Initially, two groups of farmers are identified in the study area: those who cultivate potatoes and those who cultivate wheat. In the second stage, a hundred growers altogether fifty growers from every group are surveyed for the study at random. The sample size was taken one hundred due to financial limitations. A comprehensive questionnaire was developed and data was collected on this questionnaire. The majority of the time, self-made questionnaires were implanted, which randomly selected farmers answered during interviews. The Simplex method is employed for ascertain the optimal result for the GAMS Linear Programming.

GAMS (Linear Programming Model) formation:

Software programs for computers have made it possible to quickly and efficiently calculate lengthy and intricate mathematical operations in a variety of real-world quantitative models. These programs are now an integral element of the quantitative approach to problem solving. The availability of a wide range of software packages for mathematical models allows for the incorporation of numerous activities and constraints into the

model (Reddy et al., 2008), and decision makers can readily access the results of such analysis (Sharma 2010). Leading software programs for quantitative approaches include GAMS, LINGO/LINDO, QSB, QSOM, and MS Excel solver.

One of the best methods for mathematical optimization is LP, which divides up scarce resources among conflicting demands in the most efficient way possible by making use of a number of related mathematical concepts. It describes important issues using mathematical models. Since linear programming is capable of handling many linear constraints and variables at once, it has been recommended by numerous studies as an efficient tool for a variety of agricultural decision-making problems (Weintraub et al. 2001). Numerous researchers (Sarkar & Lingard, 2002; Sethi et al., 2002; Sethi et al., 2006; Kaur et al.,2010; Gomaa et al., 2011; Wankhade & Lunge, 2012; Aparnathi, 2014; Sofi et al., 2015; Martin et al., 2015) used LP to optimize crop plans.

Following assumptions must be met in order to apply the LP optimization tool:

- Constraints
- The idea function that needs to be maximized in order to make a profit;
- Decision variables that need to be optimized.

The following provides an explanation of the GAMS linear programming model's upper components:

The optimization model comprised of sets, parameters, scalear and variables as given in table 2.

Sets	Crops	Wheat	Potato		
	Land types	Cultivated	Uncultivated		
	Periods	January	February	March	……. December
Parameters	Crop yield (kgs/acres)	Crop prices (rupees/kgs)			
Scalar	Farm size (acres)	Family labor accessible (days/month)	Hire-out wage rate (rupees/day)	Temporary labor wage (rupees/day)	Number of working days /per month
Variable	Cropping activity (acres)	Farm-net income (rupees)	Value of production (rupees)	Labor cost (rupees)	Labor income (rupees)
	Family labor use (days)'	Temporary labor (days)'			

Objective function:

Norton & Schiefer (1980), LP model directs investors in adopting land layouts to meet ideal goals, which may include maximizing benefits, minimizing expenses, or achieving each of them, within limitations of expenditure, outputs and resource accessibility. Optimizing net profit,

revenue, income, the sectors as a whole involvement, creating jobs or minimizing input expenses, water use, erosion, and natural resources depletion utilization are most often utilized objective functions in crop planning (Gomaa et al. 2011). The following is the mathematical expression for the Objective Function, which integrate the coefficients of the choice variables to achieves the goal of optimizing benefit:

$$Optimize\ Z = \sum_{i=1}^{n} C_i\, X_i$$

Constraints:

Land, labor, capital, risks, and uncertainty are just a few of the constraints that can affect any of the chosen objectives. In some cases, researchers in economic studies take into account 150–200 constraints in order to obtain results that are realistic (Reddy et al. 2008). According to observations made by Maleka (1993), (Mainuddin et al.,1997), (Weintraub et al., 2001), Sethi et al. (2002), Sarker and Lingard (2002), Srinivasa et al. (2005), Kaur et al. (2010), (Wankhade & Lunge, 2012) and (Sofi et al., 2015), Most typical objectives of agriculture optimizing using the assets at hand is profit maximization. The constraints in the model are limits connected to the resources that are available; they are expressed mathematically. To find the best objective function, the model evaluates and finds potential solutions that stay within these bounds. Constraints expressed mathematically are:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij} X_j$$

Where bi are the limits of the constraints on the other hand aij is coefficient to introduced limitations. Linear Programming Model developed which predicated the information gathered by study area's growers. Table 2 presents the data that has been analyzed. The study area's farmers own a total of one acre of land. Using their previous experience, the farmers set aside 0.50679 acres of terrain used for wheat output and 0.49321 acres for potato output. Study's goals are to determine the most advantageous cropping patterns among principal crops, optimize profit, and determine the optimal land allocation in acres for each of the major crops. The Agricultural Area, Workers, Fertilizer, and Capital are among assets. The variables used in the decision-making process are:

Z= Total Profit from every Crop; X_1 = Area allotted in acre for wheat production

X_2 = Land allotted in Acre for potato growth

The following is the LP model that was developed for this comparative study using summarized data:

Maximize Z = 450000 x1 + 640500 x2.

Subject to limitations:

constraints	
Labour	$4x_1 + 6x_2 \leq 10$
Fertilizer	$12.25x_1 + 150x_2 \leq 162.25$
Capital	$250000x_1 + 500000x_2 \leq 800000$
Land allocation	$x_1 + x_2 \leq 1$
Non-negativity constraint	$x_1 + x_2 \geq 0$

Table #2: Matrix of Linear Programming

Steps		**Wheat**	**Potato**	
Objective Function		450000	640500	**Optimize Resources**
Resources Accessible	Units			
Workers	Person days	3.0	7.0	≤ 10.0
Fertilizers	Kg	11.25	151	≤ 162.25
Capitals	Rupees	250000	500000	≤ 800000
Land	Acres	1.0	1.0	≤ 1.0

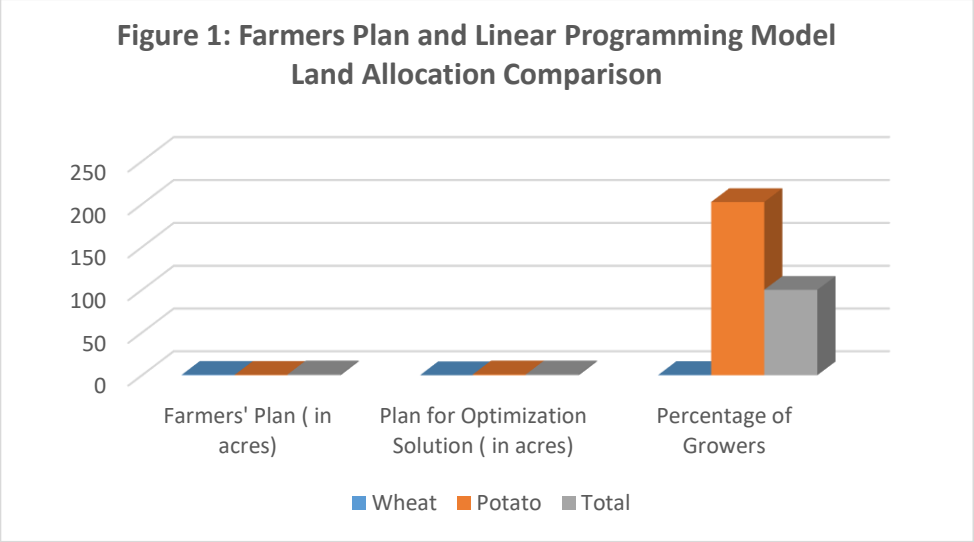
Results and Discussion:

The optimum result was obtained by developing and solving the LP model using the simplex method. In the Table # 03 shows that comparison between the farmer's decision and the best outcome for land allocation as determined by the LP model. The Linear Programming model, that indicates area for potatoes grew by 102.4 percentage on the other hand the area for wheat decreased by 99.7 percentage in contrast to the farmer's proposal, provides the best method for allocating land for the major crops. Contrast to the Linear Programming model, that suggests cropping potatoes in enormous amount in order for increase revenue and benefit by effective usage of assets, although the contrasting results demonstrated that the growers had set aside additional acres for the cultivation of wheat, the outcomes were unsatisfactory.

Table 3: Land Allocation Comparison between Farmer's Plan and LP Solution.

Produces	**Farmers' Plan (in acres)**	**Plan of LP Solution (in acres)**	**The proportion of growers.**
Staple food (wheat)	0.50679	0.0015243	0.299
Cash crop (potato)	0.49321	0.9984757	202.45
Total	1	1	100

Figure 1 presents a graph of the land allocation comparison results, which helps visualize the discrepancies between the results.



Although the farmers made use of the resources at their disposal based on their prior experiences, the LP model made the best use of the resources and increased profit. Table 4 compares the farmer's decision and the use of assets for the principal crops' under the Linear Programming model for greater clarity. The information in the Table # 03 and Table # 04 provide a clear image of the comparison between the optimal solutions and the farmers' plan. These tables lead us to the conclusion that the net profit will maximize if the farmers in the study area allocate land and use available resources in accordance with LP results up to Rs.709000 per year. This indicates an 11percent improvement over the farmer's conventional approach. Below is a tabulation of the results. The overall view of the best outcomes demonstrates that, in order to maximize profits, farmers should base their decision-making on the linear programming model. Figure 2 illustrates the outcome of the comparison of the final profit. Therefore, the results strongly suggest that it is worthwhile to try the LP model suggestions. The findings of this investigation are consistent with those of the most recent study conducted in 2020 by F. Haq, A. Parveen, S. Hussain, and A. Hussain. An LP model was created for their research in order to optimize the yield of the main crops in the Hunza district. The LP model maximizes profit and distributes land in the best way. A 10.18 percent improvement was seen when the farmer's traditional plan was compared to the results obtained from the LP model. The findings of this investigation are consistent with those of several additional studies carried out by Saini in 1975. Sivandhram and Radhakrishnan (1975). Bajwa (1978). 1995 saw Jolayemi and Olaomi. Carvalho et al. (2000), Neto et al. (1997). They discovered that the best course of action raised revenue and net profit.

Table 4: Resource Utilization Comparison

Resources	Land (Acres)	Fertilizer (kg)	Labor (Days)	Capital (Rs.)
Farmer's Plan (Acres)				
Accessible	1	162.25	10	800,000
Usage	1	50.447	3.25	300,000
Percentage of Usage	100	31.09	32.5	37.5
Non- Accessible	0	111.803	6.75	500,000
Percentage of Unused	0	68.907	67.5	62.5
Optimal Plan (Acres)				
Accessible	1	162.25	10	800,000
Usage	1	162.25	4.775	550,000
Percentage of Usage	100	100	47.75	68.75
Non- Accessible	0	0	5.225	250,000
Percentage of Unused	0	0	52.25	31.25

More labor use will increase employment due to optimal solution. The efficient resource use due to increase in profit by using same land will impact environment positively.

Table 5: Comparative Analysis of net-profit from potatoes

Farmers' plans in Rupees	Optimizing result in Rupees	Percentages increase (Growers's Plan)
640,000	709,000	110.78

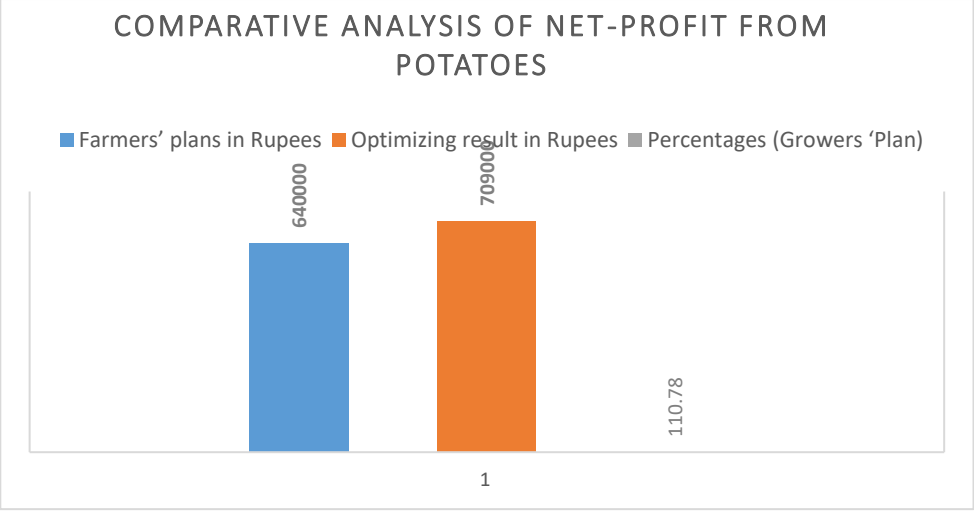


Fig2: Comparative Analysis of net-profit from potatoes

Conclusions and Recommendations:

To maximize the profit of the district Gilgit's principal crops, Linear Programming model formulated for this study. Agricultural Area is best allocated & profit is maximized by the LP model. There was an 11 percent improvement when the farmer's traditional plan was compared to the results obtained from the LP model. The optimal cropping pattern leads to shifting of cash crops for increasing profitability. Because of its highly regarded outcomes it illustrates that Linear Programming optimization is an excellent and appropriate model for usage at any circumstances involving decision choices. It also improve resource use efficiency, cost effectiveness and efficient decision making and ultimately leads to sustainability. Therefore, it is highly advised that farmers implement the optimal cropping model's recommendations in their day-to-day activities in order to maximize the benefits of the resources that are available while minimizing costs.

Farmers should focus on making the best use of resources and inputs that are currently available in order to increase production and profitability. It should be a priority to train farmers in innovative farming techniques, effective resource management, and labor allocation strategies. Furthermore, raising the price at which potatoes are sold can be achieved by expanding market accessibility and constructing transportation and storage infrastructure. Government policies should support crop development and research, provide input subsidies, and facilitate farmer financing. Growers can lower risks and ensure a consistent stream of income by planting potatoes, even though they are a more profitable crop. By adopting these recommendations, farmers in Gilgit-Baltistan can enhance their productivity and profitability, contributing to the region's economic development. Based on research findings, the following recommendations are offered to improve the agricultural sector in the studied area.

- Potatoes are a beneficial crop that should be produced in large quantities to increase the income of individuals.
- Farmers should use the best seed and fertilizer at the right ratio to increase production.
- The government's Agriculture department should hold awareness sessions for farmers about scientific methods.
- To encourage farmers to produce potatoes, the government should provide them with market infrastructure and a sufficient supply of fertilizer.

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