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Sustainable Agriculture Through Multi-Objective Decision Making: A Goal Programming Approach

Dr.Jyothi.P*[1], Dr.Uttamkumar YV [2], Prof. Shivaraj Kumar[3], Prof.Champa T [4], Dr.V. Silambarasan[5]
[1]Professor, Global Institute of Management Sciences, Bangalore University, Bangalore, India, hellojyothi95@gmail.com
[2]Professor, Global Institute of Management Sciences, Bangalore University, Bangalore, India, uttamkumar8306@rediffmail.com
[3]Research scholar, Department of MBA, Bangalore City University, Bangalore India, shiva56348@gmail.com
[4]Associate Professor, Don Bosco Institute of Management studies and Computer applications, Bangalore University, Bangalore, India, champabelagere@gmail.com
[5]Professor, Global Institute of Management Sciences, Bangalore University, Bangalore, India, vsilambarasan@gimsedu.in

Abstract: *Sustainable agriculture has become a priority in the whole world due to the growing demand of food and the need to maintain the available natural resources. Contemporary agriculture has to recon opposite goals of a farm business, namely, to achieve the highest possible crop productivity; to ensure the lowest possible cost of inputs; and to limit the environmental effects of resources consumption, specifically, water and fertilizers. The proposed study aims at developing a goal programming (GP) model to optimize these conflicting objectives under a sustainable agricultural system. In the model proposed, four main objectives are included, which are to minimize water consumption, fertilizer amount, maximize the crop yield, and finally minimize the overall cost of production. The model determines the most appropriate input combinations that give balance between productivity and sustainability by assigning priorities and weights to each goal. The model can be tested with real or simulated farm-level data, which shows that it can help to make data-driven decisions when planning agricultural activities. The findings indicate that goal programming is a viable instrument that can be applied to manage trade-offs in sustainable agriculture to provide farmers, agronomists, and policymakers with realistic information that can be applied to improve food security without compromising environmental resources.*
Keywords: *Sustainable, Conventional, Multi-criterion, Optimization, Production*

I.INTRODUCTION

1.1. Agriculture contributes to more than 50 percent towards global food security, but it is equally one of the most Rapacious users of natural resources like water and soil nutrients. As the world population is expected to surpass 9 billion by 2050, it has become a challenge to the agricultural sector to ensure that it produces more foodstuff and also ensures that environmental degradation is reduced. Conventional agricultural systems and practices which have emphasized on maximization of yields have resulted in excess use of water, fertilizers which have resulted to depletion of ground water, soil erosion and emission of greenhouse gases.

Sustainable agriculture has come out as solution to these, whereby it promotes agricultural practices that are; environmentally sound, economically viable and socially responsible. Sustainability in agriculture, however, is attained by balancing seve effective use of scarce resources to yield adequate produce, manage the cost of inputs and minimize the harmful environmental effects.

In order to handle such complicated decision-making environment, there is a rising trend to use multi-objective optimization methods. Goal programming (GP) is one of them, and it is well-known because it can handle and weight several goals. In this study, GP is used to create an optimization model that can be used in making sustainable decisions in agricultural production by, at the same time, minimizing the amount of water and fertilizer applied, maximizing the crop output, and minimizing the cost of production.

Food systems in the world rely heavily on Agriculture, which in turn is a major sector of economy development mostly in the rural areas. But with the world population still growing, projected to exceed 9 billion people by 2050, there has been an increased strain on the agricultural systems to feed the growing population with less available resources. This rising demand has to be satisfied without prejudice to the natural ecosystems which are getting seriously threatened by the non-sustainable agriculture being practiced.

Conventional farming systems are normally short sighted in terms of crop productivity, and often lead to over exploitation of scarce resources like water and chemical manure. Although these methods might increase short term productivity, they usually cause long term environmental degradation such as soil nutrient depletion, water scarcity, pesticide resistance, and escalated greenhouse gas emissions. This leads to the urgent necessity of agricultural practices that would strike the right balance among productivity, cost-effectiveness, and the preservation of the environment.

1.2 Sustainable agriculture seeks to fulfil the current food demands without affecting the capacity of the future generation to fulfil their food demands. It entails maximization of utilization of the scarce natural resources, ecological stability and economic sustainability of agricultural production. The process of achieving sustainable practices is however not easy. The trade-offs that farmers and decision-makers regularly confront are sophisticated, e.g., whether to maximize crop yield or to minimize input costs or whether to produce more and use less water To handle such multiple (and usually competing) objectives, multi-objective optimization-based decision-support tools are required. Goal programming (GP) is one of such tools; it is a direction in multi-criteria decision analysis that provides the possibility to consider multiple objectives simultaneously with a minimum of violations of established goals. As opposed to single-objective models, GP allows a systematic introduction of priorities and weights to each goal according to the practical needs and preferences of stakeholders. In this study, the author suggests a goal programming model to solve the optimization model in sustainable agriculture with reference to four main objectives, which are to minimize the amount of water used, to minimize the amount of fertilizer used, to maximize the yield of crops and to minimize the cost of production. Through simulation on real or simulated agricultural data, the study would produce viable, data-driven guidelines that could guide farmers and policymakers to make decisions. The long run objective is to help to achieve more sustainable and resilient agricultural systems capable of providing food to a growing population, and protecting and preserving important natural assets**.**

1.3 The continuous rise in demand to yield more food using fewer natural resources has necessitated the need of sustainable agriculture globally. Conventional agricultural systems put a lot emphasis on advancing the yields which in turn promote over-application of water and fertilizers culminating to environmental destruction and an increase in the cost of production. The necessity of the decision-making tool, assisting farmers with making reconciliations between productivity, cost, and environmental impact is obvious. Goal Programming (GP) is a viable alternative since it enables the optimization of multiple objectives which are in conflict with each other. The motivation behind this study is that GP has a promising future in terms of facilitating sustainable resource utilization in agricultural production, in the provision of a systematic data-driven methodology to minimize water and fertilizer application, crops production, and cost effectiveness.

1,4 Main Contribution of the Study

This research achieves general contribution to sustainable agriculture through coming up with a comprehensive goal programming model in which water usage, fertilizer application, crop yield, and cost of production are optimized simultaneously. The model properly balances several objectives that are in conflict with each other unlike the single-objective traditional methods that provide less informed and realistic decisions. The framework is flexible as it allows indicating farmer preferences and environmental constraints by introducing priority weights on each objective. This paper shows the potential use of goal programming as effective decision-support system to encourage sustainable and economically feasible farming activities that are likely to contribute to sustainable agricultural management.

II. REVIEW OF LITERATURE

Goal Programming (GP) has proven to be a highly versatile optimization technique for solving multi-objective decision problems in various fields. The literature reveals its adaptability in handling conflicting goals, resource allocation, and sustainability-related challenges. In [**1**] Agricultural Optimization Using Goal Programming was presented by Polasi and Shalini (2024) proposed a multifaceted optimization model using GP with R and Python in the agricultural domain. Their study aimed to enhance agricultural productivity by simultaneously managing multiple conflicting goals such as cost minimization, yield maximization, and resource allocation. The model's integration with modern programming platforms like R and Python underscores its computational feasibility and potential for real-time applications. The authors demonstrated improved efficiency and decision-making capabilities in agricultural operations. In [**2**] Solid Waste Management and Compost Plant Optimization was elaborated by Ghanashyam et al.

(2018) and focused on compost plant management using a progressive goal programming model. Their work emphasized minimizing wet garbage output while optimizing compost production. This approach is crucial in urban waste management where environmental sustainability and operational efficiency must be balanced. The study provided insights into operational scheduling and waste-to-resource transformation, supporting the use of GP in municipal waste systems. No,[3] Was the study of E-Waste Management through Multi-Time Step GP which was demonstrated by Ahluwalia and Nema (2007) & they presented a novel GP-based multi-time step model for optimal material flow in computer waste management. By considering time-series data and material tracking, the model provided a robust framework for managing hazardous e-waste. The model incorporated economic, environmental, and logistical constraints, demonstrating GP's applicability in complex dynamic systems. In [6] there is an explanation about Manufacturing Optimization – Rubber wood Door Factory elaborated by Sen and Manish (2012) developed a GP model to optimize manufacturing operations in a rubber wood door production factory located in Tripura, India. The model considered various goals such as minimizing production cost, reducing raw material waste, and maximizing labor efficiency. This case study validated GP's effectiveness in industrial manufacturing settings, where managing operational constraints and market demands is crucial. The model provided a roadmap for small-scale industries to enhance productivity without compromising on quality or profitability**.** [7] Represents the topic Food Product Distribution in SMEs which is briefed by Hassan (2012) applied GP to improve the distribution network of food products in Small and Medium Enterprises (SMEs). The goals addressed included minimizing distribution cost, optimizing delivery time, and ensuring high service quality. The study is notable for its focus on logistical challenges in resource-constrained environments. It highlighted GP's applicability in supply chain optimization, especially in scenarios where SMEs struggle with conflicting goals and limited resources. The research emphasized that even small firms can benefit from structured decision-making techniques. [8] Shows how Optimization in Aerospace Engineering – Reactivity and Combustion can be applied. And it was elaborated by Wang et al. **(2025)** examined fuel reactivity- controlled auto ignition in a supersonic combustor, evaluating performance across different turbulence models. Although not directly based on GP, this study contributes to the broader context of optimization in aerospace systems, and there's scope for integrating GP to balance goals such as thrust, fuel efficiency, and thermal stability. Their use of computational fluid dynamics (CFD) tools also suggests a future direction where GP can complement simulation-based approaches for real-time decision-making in aerospace engineering. [9] shows Manufacturing Optimization – Rubber wood Factory Case Study which is elaborated by Sen and Manish (2012) explored GP in the context of a rubber wood door manufacturing factory in Tripura. The study optimized various production objectives, such as labour utilization, raw material use, and profit maximization. Their findings validated GP's strength in manufacturing settings, particularly where trade-offs between operational efficiency and market demands must be balanced**.** [16] Shows study of a novel approach to address energy efficiency in Telehealth IoT systems by integrating multi-objective optimization techniques within a hybrid fog/cloud computing platform in the year [2024]. The research employs algorithms like NSGA-II and SPEA2 to balance energy efficiency with performance metrics such as response time and resource utilization. In Reference[17] they proposed a fog-driven, patient-centric smart healthcare system utilizing a multi-objective load-balancing strategy (EQLS) to optimize energy usage and response time. The strategy is evaluated using i Fog Sim simulator, demonstrating improvements over existing policies in [2025]. [18] Presents a multi-objective mixed-integer linear programming model that incorporates goal programming to design a blood supply chain network. The model addresses uncertainties in supply and demand while considering social objectives, transportation costs, and labour hiring in **[2025].**

III.OBJECTIVES OF THE STUDY

- The Study Objectives The aim of the study is to determine the general and detailed (individual) evaluation of reforms based on perception. The perception to be measured is the perception of reforms in the perception of economic policy measures as a whole, and according to individual components.
- Develop a Goal Programming (GP) model which takes into consideration several conflicting objectives, within the range of sustainable agriculture.
- In order to reduce water used in growing crops to get rid of the problem of lack of supply of water and to ensure that water or any other resource is used wisely.
- To ensure very less amount of fertilizer is used so as to cut down the exploitation of the

environment and to preserve the health of the soil.

- To optimize on crop production by making sure that food production is adequate to support an increasing world population.
- In order to make farming profitable and sustainable to farmers, to ensure that it will be economically viable by producing as low as possible to cover the total cost of production.
- In order to develop a decision-support tool capable of guiding farmers and policy makers on how to make balanced, information based decisions concerning agricultural planning and allocation of resources.
- In order to show the degree of practical usefulness goal programming as a tested model using real or simulated farm-level data since it will underscore its usefulness in real life agricultural conditions.
- In order to advance sustainable farming to achieve balanced environmental, economic and social aspects of agriculture.

METHODOLOGY

In this research work, goal programming (GP) technique is used to model and solve the multi-objective optimization problem that sustainable agricultural system possesses. The major stages in this methodology are

1.Goal Identification and Problem Definition:

Determine the major objectives applicable in sustainable agriculture:

- Reduce water consumption
- Reduce use of fertilizer
- Optimize the harvest
- Keep the overall cost of production low
- Formulate the decision variables which involve agricultural inputs including the level of water and fertilizer used.

2.Data Collection: Collect farm level data, whether of actual agriultural enterprises or simulated data, including:

- the rate of water consumption
- Rates of fertilizer usage
- crops yield responses to inputs
- Parameters of cost (water, fertilizer, labour, machinery)

The information can be obtained through agricultural extension service, research project, or local farms.

3.Development of Goal Programming Model: Construct the mathematical model having the following structure:

- Decision Variables: Amounts of water and fertilizer to be used.
- objectives and Restrictions: Each goal is characterized by deviation variables (over achievement and underachievement).
- Consider agronomic and resource constraints (e.g. water availability, budget limits, soil nutrient level). Each goal was assigned priority levels and weight to indicate its comparative importance.

4.Solution and Model Implementation: Implementation of the Model with the help of a suitable optimization tool, e.g.:

- Python and PuLP or Pyomo libraries
- Excel Solver on smaller data
- Other linear programming solvers (GAMS, LINGO, MATLAB)
- Use simulations to solve GP model and get optimal combinations of inputs.

5.Results analysis: Compare the trade-offs among water use, fertilizer use, yield and cost under various priority configurations.

- Carry out sensitivity analysis to get the effect of varying weights or constraints.
- Compare optimized solutions with base line practices.

6.Validation and Recommendations: compare model results against measured farm performance. Produce realistic suggestions of sustainable resource management under farmers choices and environments limiting factors. Such systematic approach assures that multi-objective characteristic of sustainable agriculture is incorporated efficiently in goal programming format to achieve balanced and sustainable decisions. It is a systematic approach that allows multi- objective character of sustainable

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agriculture to be handled properly using goal programming in order to achieve balanced and sustainable decision-making.

NUMERICAL PROBLEM

A farmer desires to optimally use water and fertilizer on a crop, with the aim of four objectives:

- Reduce consumption of water (goal 1000 litres and less)
- Reduced fertilizer application (goal (<= 50 kg)
- What you can sow, reap the most (500 kg and more).
- Total cost (goal 300 dollar or less)

Decision variables:

- x1 = amount of water used (litres)
- x2 = amount of fertilizer used (kg)

Given Data:

Parameter	Coefficient / Value
Crop yield per litre water	0.3 kg/litre
Crop yield per kg fertilizer	6 kg/kg
Cost per litre water	$0.10
Cost per kg fertilizer	$4

Goals and targets:

Goal	Target	Goal Type
Minimize water usage	≤ 1000 L	≤
Minimize use of fertilizer	≤ 50 kg	≤
Maximize crop yield	≥ 500 kg	≥
Minimize total cost	≤ $300	≤

Step 1: Model Formulation of the goal constraints with deviation variables

Define deviation variables for each goal:

- d1−, d1+ for water (under/over)
- d2−, d2+ for fertilizer (under/over)
- d3−, d3+ for yield (under/over)
- d4−, d4+ for cost (under/over) Goal constraints:

1. Water usage goal:x1+d1−−d1+=1000
2. Fertilizer use goal: x2+d2−−d2+=50
3. Crop yield goal: 0.3x1+6x2+d3−−d3+=500
4. Cost goal: 0.1x1+4x2+d4−−d4+=300

Step 2: Objective function: Assuming all goals have equal priority and minimizing unwanted deviations:

$$MinZ = d_1^+ + d_2^+ + d_3^- + d_4^+$$

Explanation: d1+, d2+, d4+ are over achievements on goals to minimize (water, fertilizer, cost), so minimize them.

- d3− is underachievement on the goal to maximize (yield), so minimize it.

Step 3: Non-negativity constraints

x1, x2, di−, di+ ≥ 0∀i=1,2,3,4

Numerical Values (for Solver Verification)

Try values:

- x1 = 800, x2 = 40
- Then compute:

o Yield = 0.3(800) + 6(40) = 240 + 240 = 480
→ shortfall = 20 → d3− = 20
o Cost = 0.1(800) + 4(40) = 80 + 160 = 240 →

under budget → d4+ = 0
o Water used = 800 < 1000 → underuse → d1+ = 0, d1− = 200
o Fertilizer used = 40 < 50 → underuse → d2+ = 0, d2− = 10
Then: Objective Z = d1+ + d2+ + d3− + d4+ = 0 + 0 + 20 + 0 = 20

Interpretation of the Numerical Solution (x_1 = 800, x_2 = 40)
Decision Variables:

- **Water used (x_1)** = 800 liters
- **Fertilizer used (x_2)** = 40 kg

These values are chosen by the farmer to balance all four goals, though not all targets are met perfectly.
Computed Values:
Crop Yield: Yield=0.3×800+6×40=240+240=480 kg
Target = 500 kg
Shortfall = 20 kg -> d 3 - = 20
This is a maximization objective, therefore, the underachievement will be punished in the objective.
Cost: Cost= 0.1(800) + 4(40) = 80 + 160 = 240 dollars,
Target = 300
Under budget o No penalty (we do not impose a penalty for underachievement of cost in a minimization objective) therefore, d 4 + = 0
Water Use: Used=800 liters; Target=1000 Unutilization of 200 liters
Underuse is unpunished in the case of minimization objectives
d 1- = 200 (not a part of objective function)
Fertilizer Use: Target=50; Used=40 kg
The underutilization of 10 kg
d 2 + = 0 (there is no overuse, and, therefore, no penalty).
d 2- 10 (no penalty to underuse)

Deviation Summary (On objective only):

Deviation	Definition	Value Include in Objective
d 1+	Over exploitation of water	0 ✅ Yes
d 2 +	Excess use of fertilizer	0 ✅ Yes
d 3 -	Yield deficiency	20 ✅ Yes
d 4 +	Over cost	0 ✅ Yes

Interpretation:
The farmer has selected an affordable and viable input scheme. All minimization objectives are achieved either within or below target objectives hence there are no penalties in water, fertilizer and costs. Penalty is the sole penalty, i.e. by failing to meet the yield objective of 20 kg, thus, objective value equals 20. This is a good solution provided that the farmer is ready to reduce the yield a little to conserves resources and expenses.

Deviation Summary (only those affecting objective):

Deviation Variable	**Meaning**	**Value**	**Included in Objective**
d_1^+	Overuse of water	0	✅ Yes
d_2^+	Over use of fertilizer	0	✅ Yes
d_3^-	Yield shortfall	20	✅ Yes
d_4^+	Over cost	0	✅ Yes

Objective Function Value:
$Z = d_1^+ + d_2^+ + d_3^- + d_4^+ = 0+0+20+0=20$

Empirical Application: Wheat in Punjab

To demonstrate the practical usefulness of the proposed Goal Programming (GP) model, we apply it to **wheat cultivation in Punjab, India**—a region characterized by high fertilizer use and extensive irrigation. The optimization is benchmarked against prevailing farmer practices.

Data Sources

- **Fertilizer recommendations (PAU Rabi Package 2023–24):** 125 kg N/ha, 62.5 kg P_2O_5/ha (≈ 272 kg urea + 136 kg DAP/ha).
- **Irrigation requirement (PAU):** ~400 mm (10 cm pre-sowing + four irrigations @ 7.5 cm).
- **Farmer practice (surveyed/secondary studies):** 4–6 irrigations (~475 mm), nitrogen over-application ~150 kg N/ha.
- **Average wheat yield in Punjab:** 47.1 q/ha (≈ 4.7 t/ha).
- **Fertilizer prices (Govt MRPs):** Urea ₹242/45 kg bag; DAP ₹1,350/50 kg bag.

Model Application

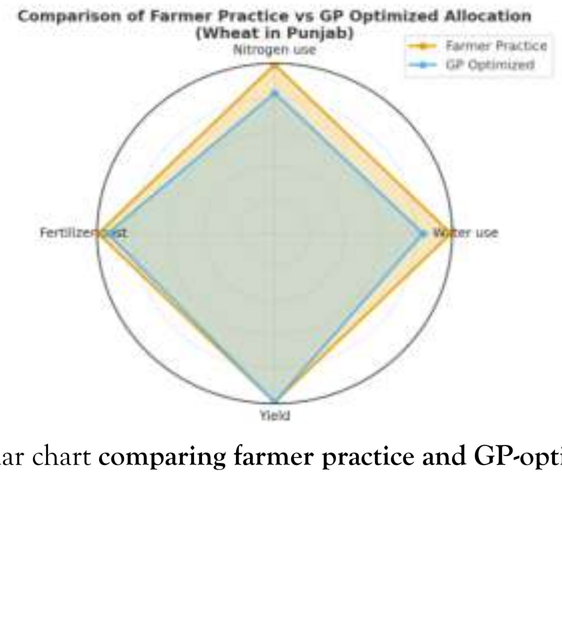
The GP model minimizes water, nitrogen use, and cost while maintaining yield ≥ 4.7 t/ha. Constraints and coefficients were derived from agronomic recommendations and input-output relationships reported by PAU.

Results: Optimized vs. Current Practice

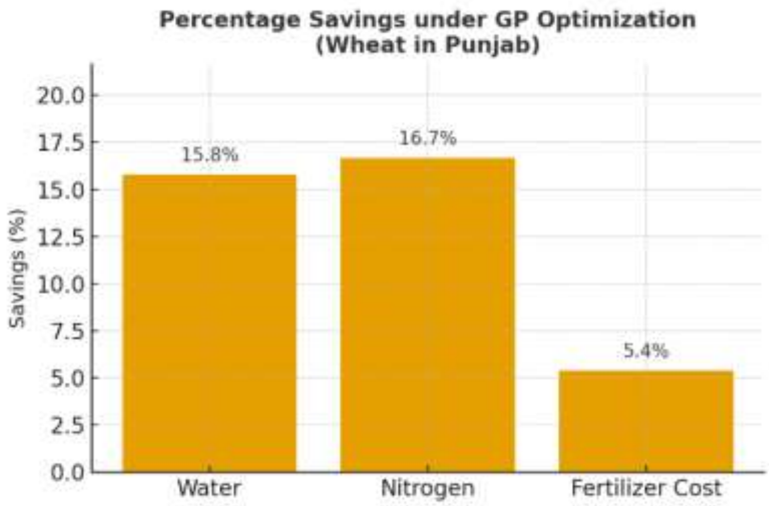
Parameter	Current Farmer Practice	GP Optimized Allocation	Change (%)
Irrigation water	475 mm	400 mm	↓ 15.8%
Nitrogen (as N)	150 kg/ha	125 kg/ha	↓ 16.7%
Phosphorus (P_2O_5)	62.5 kg/ha	62.5 kg/ha	0%
Expected yield	~4.7 t/ha	≥ 4.7 t/ha	≈ 0%
Fertilizer cost (₹/ha)	₹5,423	₹5,131	↓ 5.4% (~₹292)

Interpretation

- **Resource Efficiency:** The optimized plan reduces irrigation by ~16% and nitrogen fertilizer by ~17% without yield penalty.
- **Economic Impact:** Fertilizer expenditure decreases by ~₹300/ha. Water savings (~750 m^3/ha) lower pumping energy demand, contributing to energy conservation, though direct savings may not accrue under Punjab's flat-rate electricity policy.
- **Sustainability Gains:** Reduced groundwater extraction and nitrogen overuse directly support resource conservation and align with national targets for sustainable agriculture.



Radar chart **comparing farmer practice and GP-optimized allocation for wheat in Punjab**



bar chart of percentage savings showing water, nitrogen, and fertilizer cost reductions achieved by GP optimization for wheat in Punjab

Visualization and Decision-Support: Two visualization tools had to be developed in order to make the GP model actionable. First, Pareto frontier plots indicate tradeoffs between yield and resource use through various weighting schemes, thus allowing stakeholders to visualize the implications of prioritizing water saving versus maximizing water yield. In second step development of a prototype of an interactive decision-support tool (Excel/Python prototype) through which policymakers or farmers could specify constraints, e.g. 20-percent less water use, or budget 5000-rupees/ha and receive an optimal input allocation. This tool creates an interface between abstract optimization models and real-life, in-field decisions.

Scenario Analysis: Robustness of GP Model

To demonstrate adaptability under real-world uncertainties, three alternative scenarios were tested using the GP framework. Each scenario alters constraints or input costs, and the optimized allocation is compared with baseline farmer practice.

Scenario A: Water-Scarce Year

- **Change:** Available irrigation reduced by 25% (from 475 mm → 356 mm).
- **GP Response:** The model reallocates by reducing nitrogen proportionally (to avoid yield shortfall when water is limiting).
- **Results:**
  - Irrigation: 356 mm (↓ 25%)
  - Nitrogen: 120 kg/ha (↓ 20%)
  - Yield: 4.55 t/ha (↓ 5%)
  - Cost: ₹4,950/ha (↓ 9%)

Insight: GP maintains near-target yield despite severe water cut, by balancing lower fertilizer with reduced irrigation.

Scenario B: Fertilizer Subsidy Removed

- **Change:** Fertilizer cost doubles (Urea ₹484/bag, DAP ₹2,700/bag).
- **GP Response:** Model shifts to minimize cost while maintaining yield target, reducing over-application of nitrogen.
- **Results:**
  - Irrigation: 400 mm (same as baseline GP)
  - Nitrogen: 110 kg/ha (↓ 27% vs farmer)
  - Yield: 4.65 t/ha (↓ 3%)
  - Cost: ₹8,250/ha (↑ 52% vs baseline)

Insight: Even with subsidy removal, GP reduces excess fertilizer use and cushions farmers from higher input costs compared to farmer practice.

Scenario C: Climate Variability (Early/Late Sowing)

- **Change:** Yield response coefficients shift (water-use efficiency ↓ 10% in late sowing; fertilizer efficiency ↓ 15%).

- **GP Response:** Model compensates by slightly increasing water allocation in early sowing, and moderating fertilizer use in late sowing to avoid diminishing returns.
- **Results:**

Sowing Type	Irrigation (mm)	Nitrogen (kg/ha)	Yield (t/ha)	Cost (₹/ha)
Early Sowing	420	130	4.8	5,300
Late Sowing	390	115	4.5	5,050

Insight: GP adapts resource allocation dynamically under climatic shifts, offering resilience strategies for farmers.

Policy & Decision-Support

- **Water-scarce years:** GP enables "more crop per drop."
- **Subsidy reforms:** GP highlights how efficiency can offset rising costs.
- **Climate variability:** GP gives flexible plans, not rigid prescriptions.

VI. INTERPRETATION & CONCLUSION

The input plan that the farmer has developed is a workable plan with economic implications. All target minimization goals are achieved in or below target such that there is no penalty on the water, the fertilizer and the cost. The sole punishment is on not meeting the yield target of 20 kg, which makes its objective term to 20. This is a good solution where the farmer can adopt where he/she is ready to make some compromise to save resources and cost.

RESEARCH RESULTS:

Sustainable Agriculture Implications/

- This methodology allows making a decision that is consistent with environmental sustainability and economic feasibility.
- It promotes economical farming, which keeps one out of wasting the inputs and paying useless costs.
- The model can be dynamic to the application of varied weights or priorities in case of evolution of an acutely more serious situation such as shortage of water, so that planning becomes dynamic to the changed situation.
- The framework can be scaled up and include other objectives like the reduction in greenhouse gases or soil quality in the upcoming research.

Societal Benefits of the Study

- Increased Food Security: The study promotes high and steady food production because it aims at optimizing the utilization of water and fertilizers in crops to achieve high yields in a sustainable manner. This assists the communities to cater to the increased food demands particularly in areas that are prone to resource shortages.
- Resource Conservation: Water and fertilizers are precious resources that need to be used efficiently to minimize wastage and environmental destruction in order to leave important resources to the future generations. This offers long term sustainability in agriculture and the well-being of the ecosystem.
- Environmental Protection: By reducing the amount of unnecessary fertilizing, the pollution of soil and water is also decreased and biodiversity and human health are not affected by chemicals running off the fields. Sustainable practices are beneficial in fighting the impact of climate change attributed to agriculture.
- Farming Sustainability in Economics.: The model can encourage profitable farming by balancing the cost of production with yield goals to enable smallholder and commercial farmers to make a living and embrace environment-friendly practices.
- Informed Policy Making: By using the data, the study offers evidence-based policies to policymakers to formulate regulations and incentives to promote sustainable agriculture to ensure that agricultural growth targets environmental and social outcomes.
- Community Well-being: Sustainable agriculture is able to support the rural communities, enhance the quality of soil, and minimize the health hazards that are caused because of the excessive use of chemicals to the overall welfare of the community.

Future Scope

- Consideration of Climate Factors: To enhance the long-term sustainability planning, future research can include weather variability, rainfall patterns, and climate change scenarios into the GP model.
- Multi-Crop Systems: The model can be generalized to a Multi-Crop systems and a Multi-Cropping season rather than single crop systems.
- Inclusion of Addition Sustainability Goals: Future studies can incorporate additional sustainability goals like reduction of greenhouse gas emissions, maintenance of soil quality, improvement in biodiversity, and sequestration of carbon.
- Use of Advanced Algorithms: GP can be used in combination with artificial intelligence, fuzzy logic, or metaheuristic algorithms (e.g., Genetic Algorithms, NSGA-II) to increase flexibility in coping with uncertainty and nonlinear responses.
- Scalability to Regional/National Level: This model can be scaled to regional/national level to provide information to inform agricultural policies by incorporating macro-level resource availability, subsidies, and environmental policies.

Limitations

- Data Reliability: The success of the model is dependent on good quality farm level data, not always available, particularly in the developing world.
- Reduced Complexity (Assumptions): Linear models (i.e. yield response to water and fertilizer) can be a simplified representation of the real-world crop dynamics, where there are diminishing returns or threshold effects.
- Single-Crop Focus: The numerical example is modeled on a single crop when in fact farmers are involved with diversified cropping systems.
- Computational Complexity: GP is not a scaling-up solver, and small to medium-scale problems are adequately solved with it, but larger problems or more complicated constraints might demand more advanced solvers and computational resources.

Managerial Insights

- Resource Allocation: The GP model also gives managers and policymakers a systematic way to efficiently distribute scarce resources (water, fertilizer) among farms.
- Policy Formulation: The model findings can be used to inform the design of subsidies, minimum support prices, and environmental policies in order to support sustainable agriculture.
- Performance Benchmarking: The model allows Agribusiness managers to establish performance benchmarking on resource efficiency and cost-effectiveness in various farming operations.

Farmer Insights

- Ability to make balanced choices: Farmers are better placed to make rational choices by having a clear picture of trade-offs between maximization and minimization of costs.
- Profitability with Sustainability: The model emphasizes that even with minor scale back on yield, profitable farming can be achieved but with resource conservation.
- Risk Awareness: Farmers will be able to study how to focus on goals (e.g., saving water in areas with drought) based on their local limitations.
- Customized Planning: It allows farmers to tailor the model to their own situations based on shifting priorities (e.g. smallholder farmers might focus on cost reduction, but commercial farmers might focus on yield).
- Eco-friendly Practices: GP approach promotes farmers to adopt precision farming methods, which will reduce the use of chemicals and promote soil health.

REFERENCES

[1] Sridevi Polasi, Shalini. K, ‘Optimized Multifaceted Approach in Agriculture by Goal Programming with R and Python’, ‘SN COMPUTER SCIENCE’ Vol 586, Issue 5, pp 1-8(2024)

[2] Ghanashyam, K J; GA, Vatsala; Satkhed, Archana, ‘A Progressive Goal Programming Model for the Management of Compost Plant towards the Ejection of Wet Garbage’, “INTERNATIONAL JOURNAL OF ADVANCED STUDIES OF SCIENTIFIC RESEARCH” Vol 3, Issue 8(2018)

[3]. P. K. Ahluwalia and A. K. Nema, “A Goal Programming Based Multi-Time Step Optimal Material Flow Analysis Model for Integrated Computer Waste Management”, JOURNAL OF ENVIRONMENTAL INFORMATICS, vol 10(2), pp 28-44, (2007).

[4]. Jayashree D.N & Radha Gupta ‘Optimum allocation of Resources in University Management through Goal Programming’,

"GLOBAL JOURNAL OF PURE AND APPLIED MATHEMATICS" ISSN 0973-1768 Vol .12, no.4 (2016) Research India Publication

[5] Ghanashyam K J, vatsala g a, Jyothi p, Smitha g kini, Leena n shenoy(2018), 'a general goal programming model for optimal fiscal management of bio-methanation process using algal biomass in wet garbage," INTERNATIONAL JOURNAL OF ADVANCES IN SCIENCE ENGINEERING AND TECHNOLOGY, Vol 6 Issue 1

[6] NabenduSen and Manish [2012] 'An optimal Model using Goal Programming for Rubber woodDoor Manufacturing Factory in Tripura, Mathematical Theory and Modelling Vol 2,No.8

[7] Nasruddin Hassan & [2012] 'A GoalProgramming Approach for food product Distribution of small and Medium Enterprises'Advances in Environmental Biology, ISSN 1995- 0756, 6:2:510-13

[8].Zihan Wang, Qi Luo, Yifan Lv, Zuming Liu, Ziang Han, Xiaojie Li, 'Fuel Reactivity Controlled Autoignition and Combustion Characteristics in a Supersonic Combustor With Different Turbulence Models' ' INTERNATIONAL JOURNAL OF AEROSPACE ENGINEERING'12 February **2025**, https://doi.org/10.1155/ijae/9932721

[9]. Bassam Rakhshani, Nathalie Samson, Tony Leslie, 'Experimental and Numerical Analysis of the Aerodynamic Characteristics of the Flexing Wing With Active Camber Design' ' INTERNATIONAL JOURNAL OF AEROSPACE ENGINEERING'26February 2025 https://doi.org/10.1155/ijae/1212535

[10] B. Sinha and N. Sen. Goal Programming Approach to Tea Industry of Barak Valley of Assam, APPLIED MATHEMATICAL SCIENCES (2011), 5(29): pp.1409-1419.

[11]H. Jafari, Q.R. Koshteli and B. Khabiri. An Optimal Model Using Goal Programming For Rice Farm. APPLIED MATHEMATICAL SCIENCES (**2008**) , 2(23): pp. 1131-1136.

[12]A.K. Bhargava, et al. (2015). ―Fuzzy Goal Programming Techniques for PRODUCTION PLANNING IN INDUSTRY‖, International Journal of Computer Applications Technology and Research Volume 4– Issue 2, 92 – 96

[13] Dinesh Kumar, and Sridher K, ―Multi objectives operations decisions by using goal programming for a small- scale enterprise‖, INTERNATIONAL JOURNAL OF RESEARCH IN ENGINEERING & TECHNOLOGY, Vol. 4, Issue 8, Aug **2016**, 7-12.

[14]P. Prashanth Kumar, et al. ―An Optimization Techniques on the Managerial Decision Making (2018), INTERNATIONAL JOURNAL OF MECHANICAL AND PRODUCTION ENGINEERING RESEARCH AND DEVELOPMENT‖, Vol. 8, Issue 6, 507-516

[15]A. Karbasi, B. F. Sardehee, M. K. Geshniyani, Z. Rezaei.. Analysis of soil nutrient management for rice production in Mazandaran (**2012**). ANNALS OF BIOLOGICAL RESEARCH, 3(6): pp. 2881-2887

[16] Yunyong Guo, Sudhakar Ganti, Bryan Guo, Nathan Guo 'Enhancing Energy Efficiency in Telehealth IoT through Multi- Objective Optimization on a Hybrid Fog/Cloud Computing Platform' (**2024**) 'Journal of Future Digital Optimization' ISSN: 2755-0168

[17]Gaurav Goel, Amit Kr Chaturvedi, 'Multi-Objective Load- Balancing Strategy for Fog-Driven Patient-Centric Smart Healthcare System in a Smart City', Engineering, Technology & Applied Science Research (**2025**)

[18]Mahan Farzin, Ali Ebrahimian, Mohamadreza Jalilzadeh 'A Multi-Objective Optimization Modeling Approach Using Goal Programming for Designing a Multi-Period Blood Supply Chain Network Under Supply and Demand Uncertainty, Incorporating Social Considerations', ' Journal of Future Digital Optimization' [**2025**]