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Negotiating the Soil: From Prescriptive to Participatory Land Allocation for Agricultural Sustainability (A Bargaining Approach in Harand County, Iran)

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Abstract

Agricultural land allocation in Iran is usually prescribed top-down, which ignores conflicts among stakeholders. This study compares a prescriptive strategy, simulated with weighted goal programming (WGP), with a participatory strategy, simulated as a three-player bargaining game, for Harand County. The economic player maximizes profit, the environmental player minimizes chemical fertilizer use and the social player maximizes rural employment. Both models use farm-level technical coefficients from a survey of 150 farmers. The single-objective models show that profit conflicts with fertilizer reduction and employment, which are aligned with each other, and the WGP solution is unchanged over a wide range of weights. In the bargaining game, a bargaining equilibrium emerged after five rounds, in which the economic player conceded about 10% of its ideal profit; relative to equal-weight WGP, profit was 8.6% lower and fertilizer use 4.2% lower, with similar employment. The study contributes a framework that treats land allocation as an equilibrium of stakeholder negotiation rather than the outcome of analyst-chosen weights, and a four-year rotation scheme adapted to the county.

Keywords: Agricultural land allocation, Bargaining equilibrium, Harand County, Social participation, Sustainability, Weighted goal programming (WGP).

1. Introduction

Sustainable agriculture is vital for food security, rural employment and resource conservation, and it depends on balancing economic, environmental and social demands (Borowski and Patuk, 2021). Agro-land allocation, the distribution of land among crops under ecological constraints, is central to this balance. The push for immediate profit encourages heavy chemical inputs and labor-light farming, which damage the environment and reduce rural jobs, so allocation becomes a trade-off among profit, environmental health and social equity, particularly in developing countries.

In Iran, soil erosion and rural unemployment are major barriers: over 400,000 hectares are reported lost to erosion each year, at an estimated cost of USD 50 billion, driven by

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monoculture, excessive chemical fertilizer use and poor crop rotation (Badri, 2024), and the rural economic participation rate (42.7%) is nearly 48% below the global average (Anonymous, 2024). The government traditionally prescribes crop allocation top-down, but such schemes are costly to prepare and often ignored by farmers who prioritize economic survival. Sustainable allocation must therefore secure farmers' profit, limit environmental degradation and meet local labor needs together. This study compares the prescriptive strategy with a participatory one in which three stylized stakeholder perspectives (economic, environmental and social) negotiate. Recent studies apply multi-objective optimization to agricultural land and water allocation under economic, environmental and social goals, using genetic-algorithm and simulation models (Zhang et al., 2025; Wang et al., 2025; Wang et al., 2024; Cheng et al., 2023), food–energy–water nexus optimization (Agrawal et al., 2024), carbon-oriented allocation (Wu et al., 2022), and hydro-economic and welfare analyses (Kamaludin et al., 2021; Gohar et al., 2021). Metaheuristics are also widely used for land-use allocation, including genetic algorithms (Porta et al., 2013), the artificial bee colony algorithm (Yang et al., 2018) and the immune clonal algorithm (Ma and Zhao, 2015); Memmah et al. (2015) review them for agricultural land use. Most search for Pareto-optimal patterns for a planner to choose from and do not model how conflicting stakeholders would reach agreement. In Iran, studies have focused on land-use scenario simulation (Ghadirian et al., 2023) and multi-objective programming with economic and environmental goals (Nikouei et al., 2022).

These studies share four limitations. First, a single planner solves one optimization problem, so stakeholder conflict is reduced to analyst-chosen weights (Ma and Zhao, 2015), which introduces bias and leaves no room for negotiation. Second, rural employment is rarely an explicit objective. Third, most work at basin or regional scale with model-derived data, not farm-level coefficients. Fourth, they give a single optimal pattern without testing whether stakeholders would accept it, which matters because farmers often ignore top-down patterns. Game-theoretic multi-objective models have been used for watershed management (Moradi and Mohammadi Limaei, 2018); we apply a similar idea to crop-land allocation.

Game theory suits this conflict for two reasons. Weighted and Pareto-based methods rank objectives from the analyst's viewpoint, whereas game theory treats each stakeholder as an independent player, so agreement emerges from interaction instead of weights. Moreover, the bargaining equilibrium is a stability criterion, since no player can obtain more of its own objective without violating another player's demand, and the bargaining sequence shows each stakeholder's concessions (Moradi and Mohammadi Limaei, 2018).

Using Harand County, Iran, as a case, this study addresses these limitations in four ways: (i) three players of a bargaining game represent the economic, environmental and social perspectives, so the allocation emerges from bargaining, not analyst-defined weights; (ii) rural employment is an explicit objective alongside profit and chemical fertilizer use; (iii) the model uses farm-level coefficients from 150 farmers, validated by local experts; and (iv) the negotiated outcome is compared with a prescriptive weighted goal programming solution built on the same coefficients and constraints.

2. Methods

2.1. Research Design

Maximizing economic gain often conflicts with sustainable development, for instance through soil and water degradation or reduced rural employment. Two strategies address this tension: a top-down allocation imposed by government, prevalent in Iran, and a participatory one involving stakeholders. Both are modeled with mathematical programming, whose process has three phases (McCarl and Spreen, 2002; Figure 1).

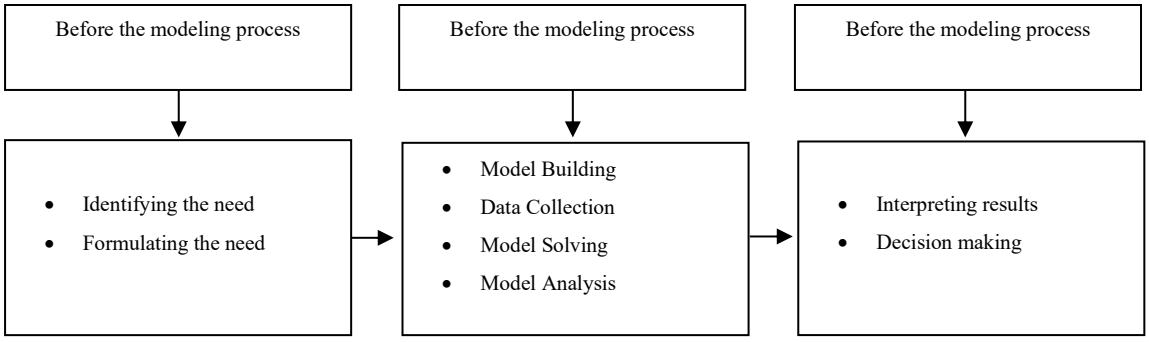


Figure 1. The process of problem solving within the context of mathematical programming.

As illustrated in Figure 1, the land allocation challenge balances three objectives: maximizing farmer profit, minimizing environmental impact, and increasing rural employment. Chemical fertilizer use is the environmental indicator because it is measured per hectare for every crop (Table 1). Because per-hectare rates are fixed, fertilizer use falls only through the crop mix, not by under-fertilizing crops, so the objective does not assume that current rates are excessive. Herbicide, pesticide and fungicide use are capped at base-year levels (Eqs. 15–17). These objectives are pursued under finite constraints on land, water and inputs, represented in Equations 1 through 5.

$$Max(Min)\ z = \{z_1, z_2, \dots, z_p\} \quad (1)$$

$$z_1 = z_1(x_i) \quad (2)$$

$$z_2 = z_2(x_i) \quad (3)$$

$$z_p = z_p(x_i) \quad (4)$$

$Subject\ to$:

$$h_j(x_i) \leq b_j \qquad i = 1,2,\dots,m \qquad j = 1,2,\dots,n \quad ; \quad x_i \geq 0 \quad (5)$$

These objectives represent the economic, environmental and social pillars of sustainable development. When decision-makers prescribe the allocation under existing constraints, the problem is modeled with Goal Programming (Charnes and Cooper, 1961), as detailed in Equations 6 to 9.

$$Min \qquad z = \{ g_1(d^+d^-),\ g_2(d^+d^-), \dots, g_n(d^+d^-)\} \quad (6)$$

$Subject\ to$:

$$h_j(x_i) \leq b_j \quad , \quad i = 1,2,3,\dots,m \quad (7)$$

$$f_i(x_i) + d_j^- - d_j^+ = w_j \quad , \quad j = 1,2,3,\dots,k \quad (8)$$

$$x_i\ , d_j^-\ , d_j^+ \geq 0 \quad , \quad d_i^- . d_i^+ = 0 \quad (9)$$

In this context, g_n denotes the n-th objective, $f_i(x_i)$ the i-th objective function generated from agro-land allocation, $h_j(x_i)$ the production factors used in the production activities, w_j the availability of the j-th production factor, and d_j^+ and d_j^- the positive and negative deviations from the intended objectives, which are to be minimized. The constraints on the availability of production factors are given in Equations 10 to 21 (Mehregan, 2013).

$$\sum A_i\, x_i + d_1^- - d_1^+ = \mathrm{g}_1 \quad (10)$$

$$\sum C_i\, x_i + d_2^- - d_2^+ = g_2 \quad (11)$$

$$\sum L_i\, x_i + d_3^- - d_3^+ = g_3 \quad (12)$$

$$\sum x_i = Total\ Agro\ \ land\ available \quad (13)$$

$$\sum Wa_i x_i \leq Total\ Water\ available \quad (14)$$

$$\sum F_i x_i \leq Total\ Fungicide\ available \quad (15)$$

$$\sum H_i x_i \leq Total\ Herbicide\ available \quad (16)$$

$$\sum P_i x_i \leq Total\ Pesticide\ available \quad (17)$$

$$\sum M_i x_i \leq Total\ Machinery\ available \quad (18)$$

$$\sum N_i x_i \leq Total\ Nitrogen\ available \quad (19)$$

$$\sum PO_i x_i \leq Total\ Potash\ available \quad (20)$$

$$\sum PH_i x_i \leq Total\ Phosphorus\ available \quad (21)$$

In Equations 10 to 21, A, C and L are the profit, fertilizer use and employment per hectare of each crop, and the other coefficients are the per-hectare requirements of each production factor (Table 1).

2.2. Simulating Prescriptive vs. Participatory Approaches

Two modeling approaches were used to allocate land: Weighted Goal Programming (WGP), representing a prescriptive strategy where a planner weighs goals to find a single cropping pattern, and Game Theory (GT), representing a participatory strategy where stakeholders negotiate a mutually agreed pattern. Because both models utilize identical coefficients and constraints, any differences in their results arise solely from their decision-making processes rather than the underlying data.

2.2.1. Weighted goal programming (WGP)

The prescriptive strategy represents a single planner who ranks the three goals. The planner's problem is a weighted goal program (McCarl and Spreen, 2002; Mehregan, 2013):

$$Min\ z = \sum \left(\frac{u_1 d_1^-}{g_1} + \frac{u_2 d_2^+}{g_2} + \frac{u_3 d_3^-}{g_3} \right) \quad (22)$$

$$\sum A_i\, x_i + d_1^- - d_1^+ = g_1 \quad (23)$$

$$\sum C_i\, x_i + d_2^- - d_2^+ = g_2 \quad (24)$$

$$\sum L_i\, x_i + d_3^- - d_3^+ = g_3 \quad (25)$$

$$h_j(x_i) \leq b_j \quad ; \quad x_j \geq 0 \quad (26)$$

where d_1^- is the profit shortfall, d_2^+ the excess of chemical fertilizer, and d_3^- the employment shortfall relative to their goals g_1 to g_3, and u_1 to u_3 are weights that sum to one. Dividing each deviation by its goal makes the three objectives, which have different units, comparable. The goals are the best values of each objective from the single-objective models (Table 3): USD 6,465,455 for profit, 59,485 units (50 kg) for fertilizer and 622,208 person-days for employment. The objective z therefore measures the weighted relative distance from the best attainable outcome on each goal.

Three weight sets were used to represent three policy stances. The first gives equal weights to the three goals ($u_1 = u_2 = u_3 = 1/3$). The second gives priority to the economic goal ($u_1 = 0.94, u_2 = u_3 = 0.03$). The third gives priority to the environmental and social goals ($u_1 = 0.21, u_2 = u_3 = 0.395$). The two non-economic goals were weighted equally because their single-objective solutions coincide (Table 3). The priority weights are the values at which the solution first departs from the equal-weight solution (Section 3.3). The model assumes linear technology with fixed coefficients (Table 1), constant returns to scale, base-year prices and exchange rate, a fixed cropland of 8,050 ha (Table 2), and resource limits in X equal to the base-year input use implied by the current allocation (Tables 1 and 2). The feasible set X is defined by the land and input constraints (Eqs. 7 and 13–21).

2.2.2. Game Theory (GT)

The participatory strategy is modeled as a multi-round bargaining game among three stylized players representing economic, environmental, and social objectives in Harand County: farmers' profit (Z_1, maximized), environmental pressure from fertilizers (Z_2, minimized), and rural employment for hired workers (Z_3, maximized). As Table 3 indicates, these interests partially conflict, with the profit-maximizing allocation yielding 24% less employment than the employment-maximizing alternative.

Before bargaining, each player's range of acceptable outcomes is obtained from the single-objective models (Table 3), with the best value of each objective as the player's ideal (Eqs. 27–29):

$$Eco_{min} \leq Eco_{Equilibrium} = Z_1 \leq Eco_{max} \quad (27)$$

$$Env_{min} \leq Env_{Equilibrium} = Z_2 \leq Env_{max} \quad (28)$$

$$Soc_{min} \leq Soc_{Equilibrium} = Z_3 \leq Soc_{max} \quad (29)$$

Each player controls one thing: the level it demands for its own objective in a round, that is, a profit floor (Eco_goal), a fertilizer ceiling (Env_goal) or an employment floor (Soc_goal), each within its range. No player chooses the land allocation directly. The allocation is computed from the demands: a player's payoff is the best value of its own objective that a feasible allocation can deliver under the demands that act as its constraints (Eqs. 30–32), where the feasible set X is defined by Eqs. 7 and 13–21 (Moradi and Mohammadi Limaei, 2018):

Economic player: $Max\ Z_1\ s.t. x \in X, Z_2 \leq Env_goal, Z_3 \geq Soc_goal$ (30)

Environmental player: $Min\ Z_2\ s.t. x \in X, Z_1 \geq Eco_goal$ (31)

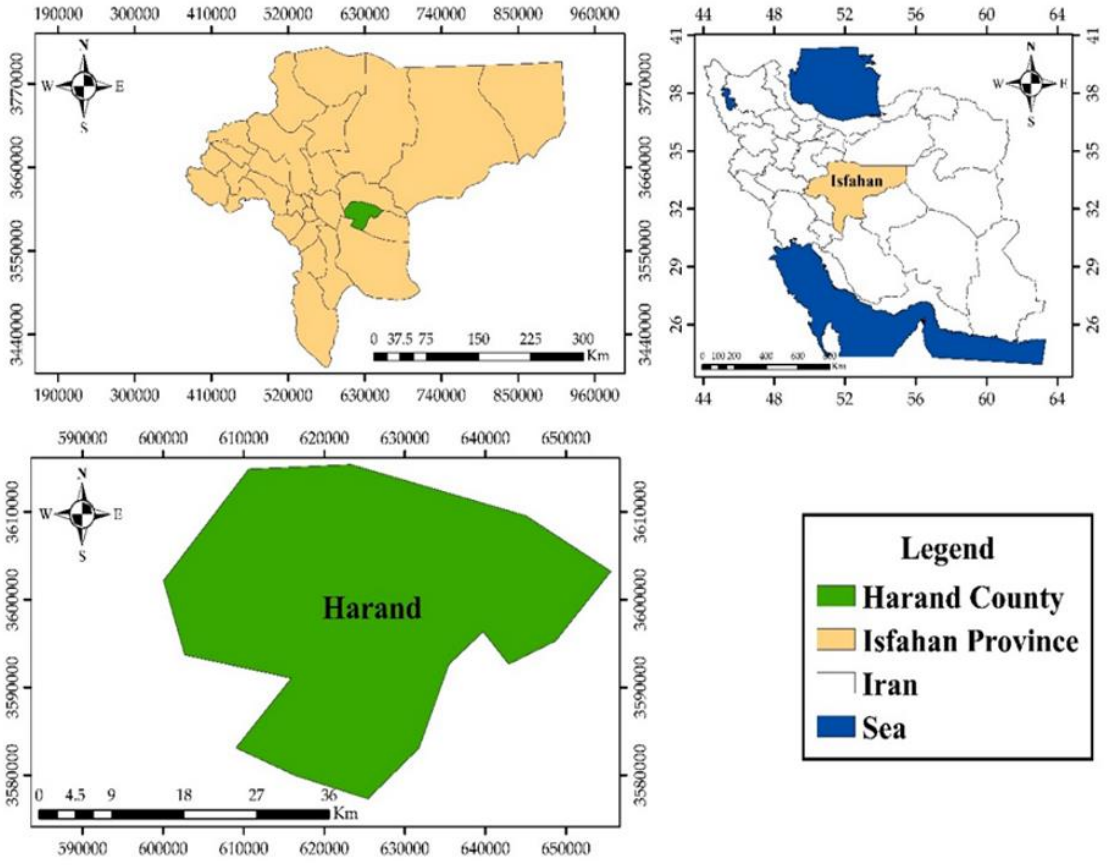
Social player: $Max\ Z_3\ s.t. x \in X, Z_1 \geq Eco_goal$ (32)

The environmental and social players treat the economic player's profit floor as a constraint while pursuing their own fertilizer ceiling and employment targets, which are met exclusively at the agreement point. Because their objectives align, they produce identical allocations across every round (Table 6), effectively forming a coalition against the economic player.

Bargaining proceeds in rounds: (1) players start with ideal demands; (2) in subsequent rounds, each announces demands and solves their own problem; (3) if demands conflict, players make preset concessions (lowering profit floors or employment floors, and raising fertilizer ceilings); and (4) bargaining stops at the agreement point (or bargaining equilibrium) where mutually consistent allocations coincide, satisfying all demands and achieving Pareto efficiency.

2.3. Study Area

Harand County lies in eastern Isfahan Province (32°34′–32°55′ N, 52°22′–52°40′ E; Figure 2) in a desert-agricultural terrain. It is a critical case for sustainable development because of intersecting challenges: severe soil erosion, rural unemployment and economic instability. Erosion, exacerbated by chemical overuse and unsustainable farming, has reduced productivity and crop yields, and this decline fuels rural unemployment in a population that depends heavily on agriculture.



208 **Figure 2.** Geographical location of the study area, Harand, Isfahan Province, Iran.

209

210 Harand County has an arid to semi-arid climate. Based on long-term records from the Varzaneh
211 / Isfahan meteorological station (1985–2020), mean annual precipitation is 120 mm, mean
212 annual temperature is 17.5 °C, and annual reference evapotranspiration is 2200 mm, so that
213 crop water demand greatly exceeds rainfall and irrigation is indispensable. The frost-free period
214 lasts about 240 days, which allows both autumn-sown (winter) and spring-sown (summer)
215 crops. Soils of the cultivated area are predominantly sandy loam to clay loam, with an average
216 electrical conductivity of 4.5 dS m^{-1} and organic matter of 0.6 % (Central Organization for
217 Rural Cooperatives & Isfahan Regional Water Authority reports). Irrigation water is supplied
218 mainly from groundwater wells and qanats, and its availability is lowest in summer, which
219 restricts the area that can be allocated to summer crops (see Section 3.2).

220

221 **2.4. Data Collection**

222 Technical coefficients were obtained from a field survey of farmers in Harand County in 2024.
223 Respondents were selected by simple random sampling. Because the population size was
224 unknown, the sample size was determined with Cochran's formula for an unknown population,
225 $n = z^2pq/e^2$, with $z = 1.96$ (95% confidence), $p = q = 0.5$ and $e = 0.08$, which gives about 150
226 respondents (Cochran, 1977). The questionnaire recorded, for each crop, the cultivated area,
227 yield and prices, and the per-hectare use of water, fertilizers (nitrogen, phosphorus, potassium),
228 herbicide, pesticide, fungicide, labor and machinery. The first 30 questionnaires were
229 completed as a pre-test to check the validity and reliability of the instrument (Cronbach's alpha
230 = 0.89). A further 120 questionnaires were then completed, giving 150 in total. The per-hectare
231 coefficients and profits were estimated as the averages of the responses for each crop. To check
232 their accuracy, the final coefficients were reviewed in interviews with five experts of the
233 Harand Agricultural Department. The models were then solved with GAMS software.

234

235 **2.5. Data Analysis Procedures**

236 To obtain the results, the economic, environmental and social objectives were first modeled
237 individually to determine their optimal outcomes (Table 3). In the second phase, WGP was
238 used to simulate the prescriptive strategy under three weight scenarios: equal weights, priority
239 to the economic goal, and priority to the environmental and social goals. The third phase used
240 GT to simulate the participatory strategy through stakeholder negotiation. Finally, the
241 outcomes of all approaches were compared, as shown in the flowchart in Figure 3.

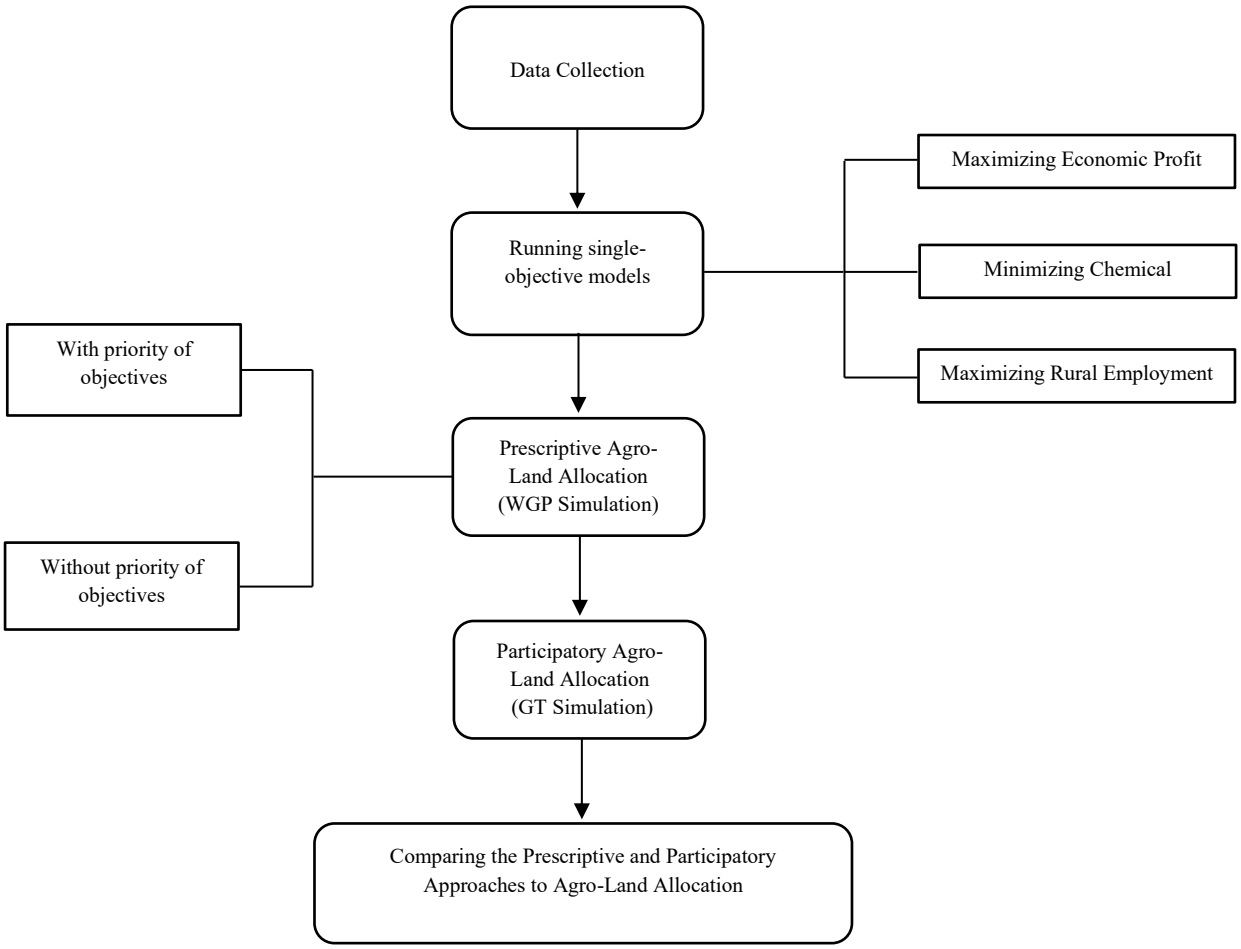


Figure 3. Research Methodology Flowchart: Steps and Procedures.

3. Results

3.1 Summary statistics of the utilized data

Table 1 gives the technical (Leontief) coefficients of the production factors required per hectare of each crop.

Table 1. Matrix of technical coefficients.

Crop/ Input	Water (m^3)	Herbicide (liters)	Pesticide (liters)	Fungicide (liters)	Nitrogen Fertilizer (50 kg)	Potash Fertilizer (50 kg)	Phosphate Fertilizer (50 kg)	Worker (person-days)	Machinery (hours)
Wheat	8000	1.82	1.45	0.41	4.6	2.43	3.03	35	21
Barley	7000	1.48	1.71	0.53	5	2.81	2.81	35	20
Alfalfa	12000	3.47	2.64	1.7	1.64	1.7	3.50	14	15
Safflower	7000	1.76	1.28	0.57	4.09	2.38	0.76	80	7
Dill	6500	1	3	0	4	0.5	3	30	10
Cotton	8000	0	0	1	5	0	0	200	8
Total Input Availability	63,855,000	14,845	12,505	4,285	35,630	19,610	21,965	319,400	149,960

Source: Research findings.

Table 2 summarizes the base-year allocation in Harand County and the resulting economic profit, chemical fertilizer consumption and employment. Wheat occupied the largest area

(5,000 of 8,050 ha), and cotton and dill the smallest. These base-year values are the reference against which the prescriptive and participatory strategies are compared.

Table 2. Economic, environmental, and social metrics in the base year.

Crop/metrics	Yield (ton/ha)	Allocated land (ha)	Economic profit (USD[1])	Consumption of chemical fertilizers (50 kg)	Labor force employment (person-days)
Wheat	4.56	5000	2727273	50300	175000
Barley	4.90	1500	134000	15930	52500
Alfalfa	14.47	500	989091	3420	7000
Safflower	2.01	1000	629091	7230	80000
Dill	35.02	30	163636	225	900
Cotton	7.98	20	39273	100	4000
Total	-	8050	4682364	77205	319400

Source: Research findings.

3.2 Running single-objective models

Table 3 presents the single-objective models. Relative to the base year, the best attainable profit is about 38% higher, the lowest chemical fertilizer use is 23% lower and the highest rural employment is 95% higher. The profit-maximizing solution conflicts with the other two goals, whereas minimizing fertilizer use and maximizing employment give identical allocations, so these two goals are aligned with each other but at odds with profit. This allocation is Pareto efficient: it is the unique optimum of both models (checked by solving them lexicographically).

Table 3. Economic, environmental, and social metrics in single-objective models.

objective	Crop/metrics	Allocated land (ha)	Economic profit (USD)	Consumption of chemical fertilizers (50 kg)	Labor force employment (person-days)
Maximizing Economic Profit	Wheat	5582	3054545	56158	195380
	Barley	0	0	0	0
	Alfalfa	388	767273	2651	5426
	Safflower	1159	730909	8382	92742
	Dill	30	163636	225	900
	Cotton	891	1749091	4455	178181
	Total	8050	6465455	71871	472629
Minimizing chemical fertilizers and maximizing rural employment	Crop/metrics	Allocated land (ha)	Economic profit (USD)	Consumption of chemical fertilizers (50 kg)	Labor force employment (person-days)
	Wheat	451	245455	4536	15783
	Barley	0	0	0	0
	Alfalfa	0	0	0	0
	Safflower	7569	4763636	54724	605525
	Dill	30	163636	225	900
	Cotton	0	0	0	0
	Total	8050	5172727	59485	622208

Source: Research findings.

The results define the range of each objective (Eqs. 33-35):

$$5172727 \leq Eco_{Equilibrium} \leq 6465455 \quad (33)$$

$$59485 \leq Env_{Equilibrium} \leq 71871 \quad (34)$$

$$472629 \leq Soc_{Equilibrium} \leq 622208 \quad (35)$$

All solutions exclude barley and allocate 30 ha to dill, the only crop feasible during summer water scarcity.

[1] . In the base year, an average US dollar corresponds to 550,000 Iranian rials.

3.3 Running weighted goal programming models

Table 4 presents the prescriptive allocation under the three weight scenarios of Section 2.2.1. Equal weights give a compromise: profit is less than 2% below its maximum, fertilizer use is about 10% above its minimum, and employment is within 0.2% of its maximum. Prioritizing the economic goal gives an allocation close to the profit-maximizing solution of Table 3, and prioritizing the environmental and social goals reproduces the fertilizer-minimizing, employment-maximizing solution. Each scenario yields a single cropping pattern.

Table 4. Results of the simulation for the prescriptive allocation of agricultural land.

Approach	Weighting of goals	Crop/metrics	Allocated land (ha)	Economic profit (USD)	Consumption of chemical fertilizers (50 kg)	Labor force employment (person-days)
Equal priority to economic, environmental and social ideals	Equal weights ($u_1 = u_2 = u_3 = 1/3$)	Wheat	3371	1836364	33915	117995
		Barley	0	0	0	0
		Alfalfa	0	0	0	0
		Safflower	3562	2236364	25754	284966
		Dill	30	163636	225	900
		Cotton	1087	2127273	5433	217328
		Total	8050	6363636	65327	621189
More priority to the economic ideal	Weighting of goals	Crop/metrics	Allocated land (ha)	Economic profit (USD)	Consumption of chemical fertilizers (50 kg)	Labor force employment (person-days)
	Priority to the economic goal ($u_1 = 0.94$)	Wheat	5549	3036364	55823	194216
		Barley	0	0	0	0
		Alfalfa	382	752727	2611	5344
		Safflower	1195	754546	8643	95634
		Dill	30	163636	225	900
		Cotton	894	1754545	4469	178770
		Total	8050	6461818	71771	474864
More priority to environmental and social ideals	Weighting of goals	Crop/metrics	Allocated land (ha)	Economic profit (USD)	Consumption of chemical fertilizers (50 kg)	Labor force employment (person-days)
	Priority to the environmental and social goals ($u_2 = u_3 = 0.395$)	Wheat	451	245455	4536	15783
		Barley	0	0	0	0
		Alfalfa	0	0	0	0
		Safflower	7569	4763636	54724	605525
		Dill	30	163636	225	900
		Cotton	0	0	0	0
		Total	8050	5172727	59485	622208

Source: Research findings.

To test whether the equal-weight solution depends on the particular weights, the weight on profit was varied while the weights on fertilizer and employment were kept equal. The WGP solution remained identical to the equal-weight solution (first scenario in Table 4) for profit weights above 0.21 and below 0.94, that is, for fertilizer and employment weights between 0.395 and 0.03 each. At 0.94 and above, the solution moves toward the profit-maximizing solution of the single-objective model, and at 0.21 and below, toward the fertilizer-minimizing, employment-maximizing solution; these boundary weights define the second and third scenarios in Table 4. The prescriptive benchmark is therefore stable over a wide range of weights and changes only when one goal receives almost complete priority. Barley received no land in any scenario; alfalfa received none in the first and third, and cotton none in the third.

Table 5 reports the sensitivity of the equal-weight solution (first scenario of Table 4) to product prices, water requirements and minimum areas of barley and alfalfa. Under uniform product price changes (-10%), the allocation, and hence fertilizer use and employment, remains unchanged because relative prices are unchanged, while economic profit varies. In contrast, a +10% increase in product prices leads to notable allocation shifts that lean more toward environmental and labor priorities, modifying the economic profit accordingly. A 10% increase in water requirements changes profit, fertilizer use and employment by less than 0.1%. Because barley and alfalfa supply regional livestock feed, a further scenario requires them to occupy 750 and 500 ha, respectively; relative to Table 4, profit then falls by 27%, fertilizer use rises by 12% and employment falls by 35%.

Table 5. Sensitivity analysis of the simulation results for the prescriptive allocation of agricultural land.

Approach	Scenario	Crop/metrics	Allocated land (ha)	Economic profit (USD)	Consumption of chemical fertilizers (50 kg)	Labor force employment (person-days)
Equal priority to economic, environmental and social ideals	Barley area = 750 ha Alfalfa area = 500 ha	Wheat	4688	2557091	47161	164080
		Barley	750	67000	7965	26250
		Alfalfa	500	98909	3420	7000
		Safflower	1750	1100909	12653	140000
		Dill	30	163636	225	900
		Cotton	332	651932	1660	66400
		Total	8050	4639477	73084	404630
	Water req. +10%	Wheat	3375	1840909	33953	118125
		Barley	0	0	0	0
		Alfalfa	0	0	0	0
		Safflower	3563	2241451	25760	285040
		Dill	27	147272	203	810
		Cotton	1084	2128597	5420	216800
		Total	8049	6358230	65335	620775
	Product prices. +10%	Wheat	451	311532	4536	15783
		Barley	0	0	0	0
		Alfalfa	0	0	0	0
		Safflower	7569	6180726	54724	605525
		Dill	30	194463	225	900
		Cotton	0	0	0	0
		Total	8050	6686721	59485	622208
	Product prices. -10%	Wheat	3371	1351342	33915	117995
		Barley	0	0	0	0
		Alfalfa	0	0	0	0
		Safflower	3562	1579472	25754	284966
		Dill	30	132726	225	900
		Cotton	1087	1650402	5433	217328
		Total	8050	4713942	65327	621189

Source: Research findings.

3.4. Running game theory models

Table 6 shows how the bargaining evolved over five rounds. For each round, it has one row per player. A row gives the objective that the player suggested for bargaining and the allocation and objective values obtained when that player solved its own problem (Eqs. 30–32). The preliminary rows give the ideal values of each player (Table 3).

Rounds 1 to 4 failed to yield agreement because players' initial demands conflicted, though gaps steadily shrank: the economic player's profit gap dropped from USD 981,818 to 218,182, while environmental and social players' gaps narrowed from 4,747 units and 797 person-days to 1,048 units and 112 person-days. With aligned environmental and social goals yielding identical allocations each round (Section 3.2), allocations converged from opposite sides, as the economic player's safflower fell from 6,873 to 5,447 ha and wheat rose from 958 to 1,997 ha, meeting the others' move from 3,617 to 5,447 ha of safflower and 3,331 to 1,997 ha of wheat. In round 5, identical allocations emerged (Table 6) at the bargaining equilibrium where all demands were fully met. Relative to ideals, the economic player conceded ~10% profit, the environmental player accepted 5.2% more fertilizer, and the social player accepted 0.09% less employment. Compared to equal weight prescriptive solutions, the participatory outcome yields 8.6% lower profit, 4.2% lower fertilizer use, and 0.1% higher employment.

Bargaining round	Ideals for agro-land allocation	Suggested objectives for bargaining	Agro-land Allocation (ha)						Objectives		
			Wheat	Barley	Alfalfa	Safflower	Dill	Cotton	Economic profit (USD)	Consumption of chemical fertilizers (50 kg)	Labor force employment (person-days)
Preliminary	Economic profit (USD)	-	5582	0	388	1159	30	891	6465455	71871	472629
	Consumption of chemical fertilizers (50 kg)		451	0	0	7569	30	0	5172727	59485	622208
	Labor force employment (person-days)		451	0	0	7569	30	0	5172727	59485	622208
First round	Economic profit (USD)	6363636	958	0	0	6873	30	189	5381818	60500	622030
	Consumption of chemical fertilizers (50 kg)	60500	3331	0	0	3617	30	1072	6363636	65247	621203
	Labor force employment (person-days)	622000	3331	0	0	3617	30	1072	6363636	65247	621203
Second round	Economic profit (USD)	6272727	1208	0	0	6530	30	282	5490909	61000	621944
	Consumption of chemical fertilizers (50 kg)	61000	3110	0	0	3920	30	990	6272727	64805	621280
	Labor force employment (person-days)	621900	3110	0	0	3920	30	990	6272727	64805	621280
Third round	Economic profit (USD)	6090909	1458	0	0	6187	30	375	5601818	61500	621857
	Consumption of chemical fertilizers (50 kg)	61500	2669	0	0	4526	30	825	6090909	63922	621434
	Labor force employment (person-days)	621800	2669	0	0	4526	30	825	6090909	63922	621434
Fourth round	Economic profit (USD)	5909091	1708	0	0	5844	30	468	5690909	62000	621769
	Consumption of chemical fertilizers (50 kg)	62000	2227	0	0	5132	30	661	5909091	63048	621588
	Labor force employment (person-days)	621700	2227	0	0	5132	30	661	5909091	63048	621588
Fifth round (Final round)	Economic profit (USD)	5814545	1997	0	0	5447	30	575	5814545	62579	621668
	Consumption of chemical fertilizers (50 kg)	62579	1997	0	0	5447	30	575	5814545	62579	621668
	Labor force employment (person-days)	621668	1997	0	0	5447	30	575	5814545	62579	621668

Table 6. Results of the simulation for the participatory allocation of agricultural land.

Source: Research findings

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According to the results presented in Table (6), Table (7) provides a summary of the findings related to the distribution of agricultural land under participatory conditions.

Table 7. Economic, environmental, and social metrics in the participatory agro-land allocation.

Crop/metrics	Allocated land (ha)	Economic profit (USD)	Consumption of chemical fertilizers (50 kg)	Labor force employment (person-days)
Wheat	1997	1089273	20094	69908
Barley	0	0	0	0
Alfalfa	0	0	0	0
Safflower	5447	3436364	39383	435776
Dill	30	163636	225	900
Cotton	575	1129091	2877	115084
Total	8050	5814545	62579	621668

Source: Research findings

3.5 Crop rotation scheme for the participatory allocation in Harand County

Table 7 outlines the single-year crop areas translated into a four year rotation for Harand County (Section 2.3). A four year cycle fits because the negotiated wheat area of 1,997 hectares comprises 24.8% of the 8,050 total, and wheat acts as a natural break crop for spring sown safflower, cotton, and dill by disrupting pathogens and balancing water and labor needs. The 8,050 hectare cropland is split into four 2,012 hectare blocks where one block rotates wheat annually (Table 8), and cotton and dill shift to prior safflower plots. This scheme closely matches the negotiated annual allocation within ~0.1% for profit, fertilizer, and employment, though safflower repeats on some land due to its 67.7% share, indicating that explicit rotation constraints are needed to enforce return intervals.

Table 8. Four-year crop rotation scheme for Harand County.

Rotation block (≈2,012 ha)	Year 1	Year 2	Year 3	Year 4
R1	Wheat	Summer crops	Summer crops	Summer crops
R2	Summer crops	Wheat	Summer crops	Summer crops
R3	Summer crops	Summer crops	Wheat	Summer crops
R4	Summer crops	Summer crops	Summer crops	Wheat

Note: summer crops are safflower, cotton and dill.

4. Discussion

Single-objective models reveal competing goals: maximizing profit yields highest income with higher fertilizer and lower employment, while minimizing fertilizer and maximizing employment yield identical allocations. This environmental-social alignment mirrors Wu et al. (2022), and the profit conflict aligns with Nikouei et al. (2022). With two players sharing positions, bargaining conflict occurs mainly between the economic player and the other two. The prescriptive WGP benchmark yields a stable compromise for profit weights between 0.21 and 0.94, collapsing under near-complete priority (Tables 3 and 4). Compared to the base year, participatory solutions raise profit by 24%, lower fertilizer use by 19%, and raise employment by 95% (Tables 2 and 6). While prior studies report baseline improvements in water-use

efficiency (Zhang et al., 2025; Wang et al., 2025), economic-ecological value (Wang et al., 2024), and trade-water use (Cheng et al., 2023), direct gain comparisons are precluded by differing objectives, regions, and baselines; unlike our bargaining model, those studies and our WGP benchmark omit stakeholder acceptance.

The participatory solution is not a dominant alternative, trading 8.6% less profit for 4.2% lower fertilizer use and marginally higher employment relative to equal-weight WGP representing another point on the same trade-off reached via concessions instead of weights, with the economic player conceding ~10% of ideal profit versus 5.2% more fertilizer and 0.09% less employment from environmental and social players. While Moradi and Mohammadi Limaei (2018) similarly applied game theory for watershed compromises, this study extends the approach to crop-land allocation using farm-level coefficients, explicit employment objectives, and a round-by-round bargaining path (Table 6) alongside a data-matched prescriptive benchmark, noting that real stakeholders might concede differently than simulated optimization models.

The zero areas of barley and alfalfa are corner solutions of a linear model without constraints for crop diversity, livestock feed or perennial crops; they are not a recommendation to farmers. When barley is fixed at 750 ha and alfalfa at 500 ha (Table 5), profit falls by 27% and fertilizer use rises by 12%, which measures the cost of these requirements. A negotiated pattern should therefore be tested with minimum-area constraints agreed with farmers before it is proposed to them.

These findings suggest potential practical advantages of the participatory strategy: negotiated patterns may increase farmer ownership and adherence, improve stability over imposed plans (Section 1), and build social capital, allowing the government to shift from issuing patterns to supporting negotiations. However, because compliance, stability, and social capital were not measured, these remain hypotheses requiring field testing.

The four-year rotation (Table 8) matches the negotiated annual allocation within ~0.1% for profit, fertilizer, and employment, demonstrating compatibility with classical land management practices. However, the high safflower share (67.7%) restricts rotation options, indicating that rotation requirements should be incorporated as explicit constraints in future models.

5. Conclusions

This study compared a prescriptive and a participatory strategy for allocating cropland in Harand County. Profit conflicts with fertilizer reduction and employment, which are aligned with each other. The prescriptive benchmark is stable over a wide range of weights, and the bargaining game reached a bargaining equilibrium after five rounds, with a modest profit sacrifice (8.6% relative to equal-weight WGP) for lower fertilizer use.

This study contributes methodologically by integrating weighted goal programming with a multi round bargaining game using identical coefficients for direct process comparison; theoretically by treating land allocation as a stakeholder strategic equilibrium and revealing round by round convergence mechanisms; and practically by providing a replicable arid region planning procedure and operational rotation scheme, addressing the critical yet often overlooked role of stakeholder acceptability alongside optimality.

This study has key limitations: simulations replaced real stakeholders, data cover only one county and year, linear models use fixed coefficients without uncertainty, sensitivity analyses tested only the WGP model rather than the bargaining game, rotation was excluded as a constraint, and compliance, stability, and social capital remained unmeasured. In addition, rural employment is one measurable indicator of the social dimension; income distribution and equity are not captured. Future research should test the framework with real stakeholder workshops in other regions, include uncertainty (fuzzy or stochastic programming) and rotation constraints in a dynamic model, and compare it with alternative multi-objective approaches such as NSGA-II and artificial bee colony, genetic and clonal selection algorithms.

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مذاکره بر سر خاک: از تخصیص زمین تجویزی تا مشارکتی برای پایداری کشاورزی (رویکردی چانه‌زنی در شهرستان هرند، ایران)

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چکیده

تخصیص اراضی کشاورزی در ایران معمولاً به صورت از بالا به پایین تجویز می‌شود که تضاد میان ذینفعان را نادیده می‌گیرد. این مطالعه یک راهبرد تجویزی، شبیه‌سازی‌شده با برنامه‌ریزی ریاضی آرمانی وزنی، را با یک راهبرد مشارکتی، شبیه‌سازی‌شده در قالب یک بازی مذاکره‌ای سه طرفه، برای شهرستان هرند مقایسه می‌کند. بازیکن اقتصادی به دنبال حداکثرسازی سود، بازیکن زیست‌محیطی به دنبال حداقل‌سازی مصرف کود شیمیایی و بازیکن اجتماعی به دنبال حداکثرسازی اشتغال روستایی است. هر دو مدل از ضرایب فنی در سطح مزرعه حاصل از پیمایش ۱۵۰ کشاورز بهره می‌برند. مدل‌های تک‌هدفه نشان می‌دهند که سود با کاهش کود و اشتغال در تضاد است (در حالی که دو مورد اخیر با هم همراستا هستند) و پاسخ برنامه‌ریزی ریاضی آرمانی وزنی در بازه وسیعی از وزن‌ها تغییر نمی‌کند. در بازی مذاکره‌ای، تعادل مذاکره پس از پنج دور حاصل شد که طی آن بازیکن اقتصادی حدود ۱۰ درصد از سود ایده‌آل خود را واگذار کرد؛ مقایسه این خروجی با برنامه‌ریزی ریاضی آرمانی وزنی با وزن‌های برابر نشان داد که سود 8/6 درصد کمتر، مصرف کود 4/2 درصد کمتر و میزان اشتغال در حد مشابهی بوده است. این مطالعه چارچوبی را ارائه می‌دهد که تخصیص اراضی را به عنوان تعادلی ناشی از مذاکره ذینفعان به جای نتیجه وزن‌های انتخاب‌شده توسط تحلیل‌گر تلقی می‌کند و یک طرح تناوب زراعی چهارساله متناسب با شرایط شهرستان تدوین می‌نماید.