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Research article

Determination of optimal cropping plan for dryland agrosilvipastoral systems in western Tamil Nadu

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Abstract
Indian rainfed agriculture is highly vulnerable to climate change and other factors, including topography, land size, and soil management practices. Consequently, optimizing cropping patterns is crucial for enhancing resilience and profitability. The study employed the MOTAD model to explore alternative cropping strategies for crop-livestock dryland farms under varying climatic risks. The research focused on western Tamil Nadu, a drought-prone region in south India's rain-shadow zone, where agrosilvipastoral systems incorporating *Cenchrus ciliaris* grass and *Acacia spp* trees support livestock rearing. Based on a survey of 180 farmers, a representative six-hectare farm was optimized across different risk levels. The results revealed that under optimal cropping patterns, high-risk farms have a maximum of 60% area allotted to silvipasture, about 26% for profitable black gram, and only 9 and 6% to the sorghum and horse gram, respectively. This strategic land allocation adjustment significantly improves farmers' net returns compared to existing practices, offering insights into risk-informed farm planning for enhanced sustainability.

Keywords: Agrosilvipastoral system, Dryland agriculture, Dryland farming, MOTAD Model, Optimal cropping pattern, Risk programming

Introduction
Dryland areas across developing nations cover approximately 3 billion hectares, accounting for about 41% of the global area, and are home to 2.5 billion people. Among this population, around 16% live in chronic poverty (CGIAR, 2012). India is a leading country in dryland agriculture, both in terms of area and value of production (Mohanasundari and Shanmugam, 2015b). This type of agriculture is practiced across two-thirds of India's total cropped area, which amounts to 162 million hectares (66%) (Sengupta and Mohanasundari, 2023). Dryland agriculture backs up to 40% of the country's food supply (Asha *et al*., 2012).

By 2050, India will need to produce 377 million tonnes of food grains to feed its projected population of 1.7 billion (Khangar and Thangavel, 2024). This target cannot be met through irrigated areas alone, as the current irrigation potential covers only 178 million hectares (Saravanakumar *et al*., 2022). Improving dryland agriculture is very important for achieving the nation's food security and sustainable economic growth, in addition to enhancing the living standard of the farming community. Drylands' food production is influenced by the amount and distribution of rainfall, which is about 400 mm to 1000 mm per annum. Rainfall patterns are becoming erratic, with some regions receiving less than 500 mm annually (Kumar et al., 2023). Due to their limited natural resources, drylands confront severe environmental restrictions that are made worse by climate change.

Silvopastoralism, a type of agroforestry, promotes ecological interactions that improve agricultural sustainability (Chappa *et al*., 2024), combining woody vegetation and grazing cattle. Similarly, Agroforestry techniques that combine trees, crops, and cattle to improve land productivity and sustainability are known as agrosilvipastoral systems (ASPS). These agroforestry systems improve soil fertility, retain more water, and help to control erosion. As silvipastoral systems (SPS) combine trees, shrubs, and cattle provide various benefits in terms of reducing climate variability by regulating temperature and advancing drought resistance (Dagar and Gupta, 2020; Yildiz and Cacan, 2023). The ASPS also reduces the economic vulnerability of farmers by offering a variety of revenue streams, including wood, fodder, fruits, and livestock products in addition to crop income (Shashikumara *et al*., 2024), which is not possible through traditional dryland farming.

Additionally, the ASPS helps in arresting the deterioration of forests and land by substantial environmental conservation (Moreno and Rolo, 2019; Ortiz *et al*., 2023). ASPS contributes to climate change mitigation due to its significant role in carbon sequestration both above and below ground (Khan *et al*., 2024; Sahoo *et al*., 2022; Yadav *et al*., 2019). Unsustainable grazing practices or intensive chemical usage in farming could wipe out the benefits of these systems. Instead, strategic grazing and forest management techniques that optimise carbon storage in soil and vegetation are necessary to realise this potential.

Materials and Methods

Study area and sampling design: The study area, Western Tamil Nadu, which includes the districts namely, Tiruppur, Erode, Karur and Coimbatore and located in the rain-shadow region of South India. This is a drought-prone area where unique agrosilvipastoral systems are followed. The common agroforestry practices are bund and border planting with Indian Tulip Tree (*Thespesia populnea*), Albizzia (*Albizia lebbeck)*, Subabul (*Leucaena leucocephala),* Anjan Tree or Indian Blackwood (*Hardwickia binata),* Ailanthus (*Ailanthus excelsa),* Tapioca (*Manihot esculenta)* (also known as Cassava), Groundnut (*Arachis hypogaea),* Gingelly (*Sesamum indicum),* Cotton (*Gossypium spp.)* are intercropped with *Eucalyptus spp.,* and block plantation of Teak (*Tectona grandis)* and Eucalyptus are practiced under garden land conditions. Under this agrosilvipastoral system, Velvel (*Acacia leucophloea*) is allowed to grow in rainfed lands with naturally emerging perennial grasses, such as Kolukattai *grass* or Buffel grass (*Cenchrus ciliaris*) (Kumar *et al*., 2011; Nagar and Meena, 2021). Sheep rearing is a popular subsidiary occupation in this area (Mohanasundari and Shanmugam, 2015a).

Data analysis:

The Mean-Absolute Deviation (MOTAD) model has been widely explored in agricultural economics as an alternative to quadratic risk programming for farm planning under uncertainty. Research has shown that by reducing departures from expected returns, MOTAD is one of the efficient methods of risk management, which is simpler to compute. It is a preferred option in many situations due to its advantages over quadratic programming, as noted by Hazell (1971).

Lopez's (1977) study highlighted MOTAD's effectiveness in identifying an income-risk frontier by contrasting it with other risk programming approaches. We can form risk-efficient dry farm designs for our country using this model. For example, in a study conducted at arid tracts of Western Tamil Nadu, MOTAD programming was used to develop effective agricultural designs under different dry farming conditions (Sekhar and Palanisami, 2000).

MOTAD model formulation: Minimize the mean absolute deviation (M) for a given expected profit level. Objective function:

$$\min M = \frac{1}{T}\sum_{t=1}^{T} Y_t$$

Where, M= Mean absolute deviation of farm income; T = Number of years considered (2009-10 to 2014-15); Y_t = Negative deviation of gross margin from the mean in year t

Subject to: Expected gross margin constraint**:**

$$\sum_{j=1}^{n} G_j X_j \geq Z$$

Where, G_j = Mean gross margin per unit of the jth crop or livestock activity; X_j= Decision variable representing the level of activity for the jth crop or livestock; Z = Minimum expected farm income

$$Deviation\ Constant: Y_t \geq Z - \sum_{j=1}^{n} G_{jt} X_j, \quad \forall t$$

Where, G_{jt} = Gross margin of the jth activity in year t

Resource constraints:

Land: $Land: \sum_{j=1}^{n} A_j X_j \leq A$ A_j is the land required per unit of activity and A is total land available	**Labor:** $Labour: \sum_{j=1}^{n} L_j X_j \leq L$ L_j is the labour required per unit and L is the total available labour
Capital: $Capital: \sum_{j=1}^{n} C_j X_j \leq C$ C_j is capital requirement per unit and C is total capital available.	**Water:** $Water: \sum_{j=1}^{n} W_j X_j \leq W$ W_j is water requirement per unit and W is total available water.
$Non-Negativity\ Constsnt: X_j \geq 0, \quad Y_t \geq 0, \quad \forall j,t$	

By integrating risk programming, the MOTAD model identified optimal land allocation strategies that balance risk and profitability. The findings provide valuable insights into sustainable dryland farming practices, particularly in regions prone to climatic variability. The optimized farm plans are discussed in the subsequent section, where the results illustrate the effectiveness of strategic diversification in managing agricultural risks.

Results and Discussion

Optimization of farm resource allocation under risky conditions: Optimal allocation of farm resources across diverse enterprises is an important strategy for risk management, provided the optimization problem explicitly incorporates risky situations into the modeling process. In the present study, one model farm, which is representative of an average farm size, was selected and optimized. The first stage of MOTAD is maximizing profit under normal conditions using linear programming. The second stage minimizes the income deviation under risky situations, and the optimal plan is generated from the solution.

Optimal crop plan for the western TN: The optimized allocation of resources for an integrated crop-livestock system was recorded (Table 1). The results indicate that, in the optimal scenario, the area allocated to the fodder crop *Cenchrus ciliaris* within the silvipasture system was maximized to 3.3 hectares. Meanwhile, the land area under horse gram cultivation was significantly reduced from 1 hectare in the existing system to 0.27 hectares. Similarly, the area allocated to fodder sorghum decreased from 1 hectare to 0.51 hectares. However, due to its profitability, black gram cultivation increased from 1 hectare to 1.42 hectares, representing a net increase of 0.42 hectares. Despite the overall reduction in cultivated area from six to 5.5 hectares, the farmer's net income increased by 32.8%, from Rs 61,327 to Rs 81,470. This highlights the importance of adjusting cropped areas in response to limited water supply, ensuring effective use of scarce resources while minimizing risk.

The negative deviation from the expected gross return is used as a measure of risk, parameterized across feasible ranges. This risk is bounded by a lower limit of Rs 58,000 (λmin) and an upper limit of Rs 1,53,785 (λmax), representing the maximum allowable deviation. The upper bound corresponds to the maximization scenario, while the lower bound represents the minimum achievable risk, which can be obtained by setting risk minimization as the objective of the model. To assess the impact of different risk levels on farm planning, the model was solved for risk levels of Rs 1,53,785, Rs 1,30,000, Rs 1,10,000, Rs 95,000, Rs 75,000 and Rs 58,000. The results for these risk levels have been summarized (Table 2).

***Land allocation at maximum risk condition*:** The mathematical model's results suggest that when farmers operate under high-risk conditions (λ = Rs 1,53,785), a substantial 60% of the total land is allocated to silvipasture (Fig 1). Black gram, being a profitable crop, is assigned 26% of the total land area. Sorghum accounts for 9% %, while horse gram is given the smallest share at 5%. Here, λ represents the expected gross income. According to Shanmugam and Palanisami (1993), farmers tend to accept greater risk in pursuit of higher income, whereas they may opt for lower earnings when seeking to minimize risk. In this scenario, the farmer anticipates a gross income of Rs 1,53,785 under high-risk conditions. Figure 1 to 3 visually represents land allocation under maximum risk. The findings align with Malaiarasan *et al*. (2021), who emphasize that an optimal crop mix can enhance productivity by mitigating pest and disease pressures, improving soil health, and increasing ecological efficiency within production systems.

***Farmland allocation at medium risk condition*:** As illustrated in Fig 2, farmers opting for a medium-risk strategy must accept a notable reduction in income, from Rs 1,53,785 to Rs 1,11,000, reflecting a decrease

Table 1. Optimal crop plan of agrosilvipastoral system of Tiruppur district

Crop	Units	Existing area	Percentage to gross area	Optimal crop area	Percentage to gross area	Change
Total Farm size	ha	6	-	**5.5**		-0.5
Fodder Sorghum	ha	1	16.67	0.51	9.27	-0.49
Horse gram	ha	1	16.67	0.27	4.91	-0.73
Black gram	ha	1	16.67	1.42	25.82	0.42
Silvipasture	ha	3	50	3.3	60.00	0.5
Sheep	No.	30	-	56	-	26
Milch animal	No.	6	-	8	-	2
Capital	Rs	72,650	-	72,315	-	335
Gross income	Rs	1,33,977		1,53,785		19,808
Net income	Rs	61,327	-	81,470	-	20,143

Table 2. Land allocation to different risk levels

S. No	Components	Land allocated (ha)					
Lamda (Gross return in Rs)		153785	130000	110000	95000	75000	58000
1	Sorghum	0.51	0.42	0.29	0.57	0.51	0.12
2	Horse gram	0.27	0.32	0.38	0.22	0.09	0
3	Black gram	1.42	1.35	1.4	0.59	0.52	0.43
4	Silvipasture	3.3	3.19	3.02	3.66	3.73	3.86
Total area		5.5	5.28	5.09	5.04	4.85	4.41

of Rs 42,785. This reduction highlights the trade-off between risk exposure and income security. Under moderate risk, the optimal land allocation strategy shifts to balance profitability with risk mitigation. The model indicates that silvipasture remains the dominant land use, occupying 59% of the total land area. Black gram cultivation increases to 28%, reinforcing its role as a stable and profitable crop under medium-risk conditions. Sorghum allocation is further reduced to 6%, signifying a strategic move away from this crop when risk aversion is a priority. Meanwhile, the area allocated to horse gram rose to 7%, up from 5% in the high-risk scenario, suggesting that farmers value their stability and contribution to overall farm resilience under moderate risk exposure.

Farmland allocation at minimum risk condition: As the level of risk decreases, the model predicts a corresponding drop in farmer income to Rs 58,000. Fig 3 illustrates that, under low-risk conditions, there is a significant shift in land allocation strategies. The proportion of land dedicated to silvipasture expands substantially to 87%, underscoring its role in ensuring farm stability under adverse conditions. Black gram accounts for 10% of the total land area, while sorghum is allocated a minimal 3%. Notably, horse grams are entirely excluded from the low-risk land-use plan. The land-use percentages under different risk levels have been summarized (Figs 1-3). The results indicate the importance of alternative farm planning with available resources to mitigate the risk while optimizing income. The results of the MOTAD model demonstrate that income is determined based on the risk-taking ability of the farmers (*Udo et al., 2015; FAO, 2013)*. The farmers operating under high-risk conditions tend to choose high-return crops, such as black gram, despite the issues associated with them. However, under medium and low-risk scenarios, the land allocation shifts towards more stable but lower-income crops such as livestock-based silvipasture and sorghum.

The study clearly describes a shift in cropping patterns that aligns with previous research, indicating that diversification strategies can enhance resilience by

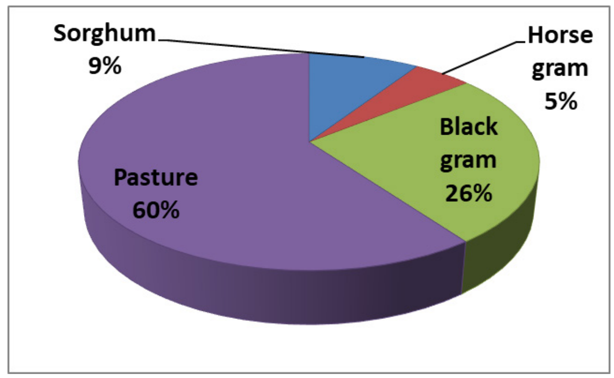

Fig 1. Land allocation with maximum risk (λ = 1,53,785)

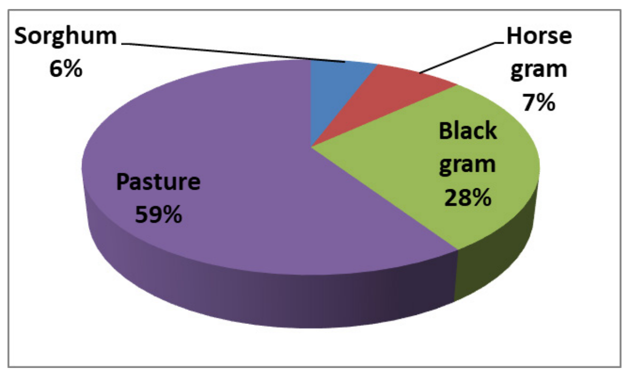

Fig 2. Land allocation with medium risk (λ = 1,10,000)

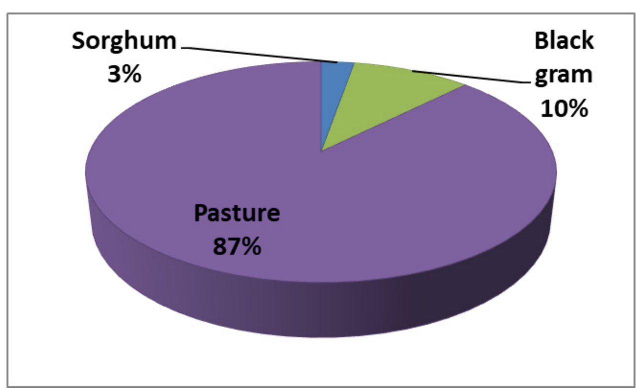

Fig 3. Land allocation with minimum risk (λ = 58,000)

reducing dependency on high-risk crops. For example, Malaiarasan *et al.* (2021) mentioned in their study that rightly planned crop diversity can improve soil health, reduce pest and disease outbreaks, and increase ecological sustainability overall. Some studies (Hedarkar *et al*., 1997; Osumba *et al*., 2021; Mishra *et al*., 2024) indicate that policymakers should prioritise the best land-use plans by considering farmers' differing risk tolerances and resource limitations.

Additionally, despite a decrease in the overall cultivated area, the research farm's net revenue increased significantly, demonstrating the efficiency gains possible through effective land allocation. According to Kumar *et al.* (2024), the study emphasises how crucial it is to incorporate risk-based modelling into agricultural decision-making procedures to successfully strike a balance between sustainability and profitability. To further improve these optimisation techniques, future studies should investigate the incorporation of other variables like market volatility, climatic variability, and policy incentives.

Conclusion

In addition to geography, land size, and soil management techniques, climate change poses a serious threat to Indian rainfed agriculture. Therefore, improving resilience and profitability requires cropping pattern optimisation. The MOTAD model was used in this study to investigate different cropping approaches for crop-livestock dryland farms under various climate hazards. The study focused on Western Tamil Nadu, a drought-prone area in the rain-shadow zone of South India, where livestock production is supported by agrosilvipastoral systems that include Acacia spp. trees and *Cenchrus ciliaris* grass. A representative six-hectare farm was optimised across various risk categories based on a survey of 180 farmers. The findings provided information on risk-informed farm planning for improved sustainability and showed that strategic changes to land allocation greatly increased farmers' net profits when compared to current methods.

The findings indicated that silvipasture remains a profitable and stable option, particularly in low-risk scenarios, due to its low water requirements and maintenance costs. Farmers facing high risk diversify their cropping choices, incorporating horse gram despite its volatility, while risk-averse farmers favour sorghum for stability. Black gram, despite its risk, remains attractive due to its high market price. Under water scarcity, livestock farming provides a reliable return, reinforcing the importance of diversified farming strategies. Overall, as risk levels increase, diversification becomes a crucial strategy for managing uncertainties and optimizing farm performance.

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