



International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

© Agronomy

www.agronomyjournals.com

2024; 7(4): 132-135

Received: 22-02-2024

Accepted: 25-03-2024

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GIS-based crop suitability analysis for rainfed agriculture in the Puebla-Tlaxcala Valley, Mexico

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DOI: <https://doi.org/10.33545/2618060X.2024.v7.i4b.4988>

Abstract

For example, in the Puebla-Tlaxcala valley of central Mexico, nearly 70% of cropland depends entirely on rainfall, yet no spatially explicit suitability assessment exists for the region's five main rainfed crops. This research applied GIS-based multi-criteria evaluation (MCE) with analytic hierarchy process (AHP) weighting to map land suitability for maize, bean, wheat, barley, and oat across 4,820 km² of the valley. Seven biophysical factors rainfall, temperature, soil depth, slope, soil pH, organic matter, and drainage were evaluated against FAO crop requirements. Barley showed the largest highly suitable area (31.6%), followed by maize (28.4%) and wheat (22.3%). Bean and oat had more restricted suitability due to sensitivity to waterlogging and frost, respectively. Rainfall and temperature were the most influential factors across all crops (combined weight 0.41–0.47). The suitability maps achieved 82.4% agreement with existing land use patterns. These maps can guide crop allocation decisions and identify zones where alternative crops may outperform current practices.

Keywords: Crop suitability, geographic information systems, multi-criteria evaluation, analytic hierarchy process, rainfed agriculture, puebla-tlaxcala valley, land evaluation, maize, bean, spatial analysis

Introduction

Take the Puebla-Tlaxcala valley as an example: over 180,000 smallholder farmers grow maize and beans on rainfed plots averaging 2.3 hectares, yet crop allocation is based largely on tradition rather than evidence of biophysical suitability [7, 9]. This mismatch between land capability and crop choice contributes to yield gaps exceeding 40% across the valley. GIS-based land suitability analysis offers a systematic approach to matching crops with their optimal environments by integrating spatial data on climate, soils, and terrain [3, 5].

The FAO framework for land evaluation [1] provides a widely adopted structure for classifying land into suitability classes (S1 through N), while multi-criteria evaluation methods allow simultaneous consideration of multiple biophysical factors with expert-assigned weights [4, 15]. The analytic hierarchy process (AHP) is the most common weighting method in agricultural GIS applications because it quantifies expert judgment while checking for logical consistency [6, 16]. Ceballos-Silva and Lopez-Blanco [9] applied MCE to delineate suitable areas for crops in central Mexico but covered only two crops and did not include soil chemical properties.

This research extended the MCE-AHP approach to five crops across the full Puebla-Tlaxcala valley, incorporating seven biophysical factors from high-resolution spatial datasets. The objectives were to map suitability classes for each crop, identify the most influential environmental factors, and validate the maps against current land use records.

Materials and Methods

Study area description

The Puebla-Tlaxcala valley lies between 19.0° and 19.6° N latitude at 2,100–2,800 m elevation in central Mexico. The climate is temperate sub-humid (Cwb) with mean annual rainfall of 750–1,100 mm concentrated in June–October. Soils range from volcanic-origin Andosols and Cambisols on slopes to alluvial Phaeozems in the valley floor [7]. About 68% of cultivated land is rainfed, with maize occupying 54% of cropped area.

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Materials

Spatial data layers included: INEGI 30-m DEM for slope and elevation; CONAGUA climate normals (1981–2010) interpolated to 250 m resolution for rainfall and temperature; INIFAP soil survey at 1:50,000 scale for depth, pH, organic matter, and drainage class. All layers were projected to UTM Zone 14N and resampled to 250 m grid cells. Crop requirements were compiled from FAO [2] and Sys *et al.* [2] for the five target crops [9].

Methods

Each factor layer was reclassified into four suitability classes

(S1, S2, S3, N) following FAO guidelines. AHP pairwise comparison matrices were constructed by three agronomy and two soil science experts, yielding factor weights with consistency ratio (CR) < 0.10 [4]. Weighted overlay analysis combined the reclassified layers in ArcGIS Pro 3.0. Validation compared suitability maps against INEGI land use/cover data (2017 edition) using an error matrix with 300 stratified random points. Overall accuracy and kappa statistic were calculated [3, 12].

Results

Table 1: Suitability class distribution (% of study area) for five rainfed crops

Crop	S1 (%)	S2 (%)	S3 (%)	N (%)
Maize	28.4	34.1	22.8	14.7
Bean	18.7	29.3	31.4	20.6
Wheat	22.3	31.8	27.1	18.8
Barley	31.6	28.4	24.3	15.7
Oat	15.2	27.6	33.8	23.4

S1=highly suitable, S2=moderately suitable, S3=marginally suitable, N=not suitable

Table 2: AHP factor weights for crop suitability evaluation

Factor	Maize	Bean	Wheat	Barley	Oat
Rainfall	0.24	0.22	0.20	0.19	0.21
Temperature	0.23	0.21	0.24	0.22	0.20
Soil depth	0.16	0.14	0.15	0.17	0.16
Slope	0.14	0.15	0.13	0.14	0.16
Soil pH	0.10	0.13	0.14	0.12	0.11
Organic matter	0.08	0.09	0.08	0.09	0.10
Drainage	0.05	0.06	0.06	0.07	0.06

All CR < 0.10. Weights sum to 1.00 per crop

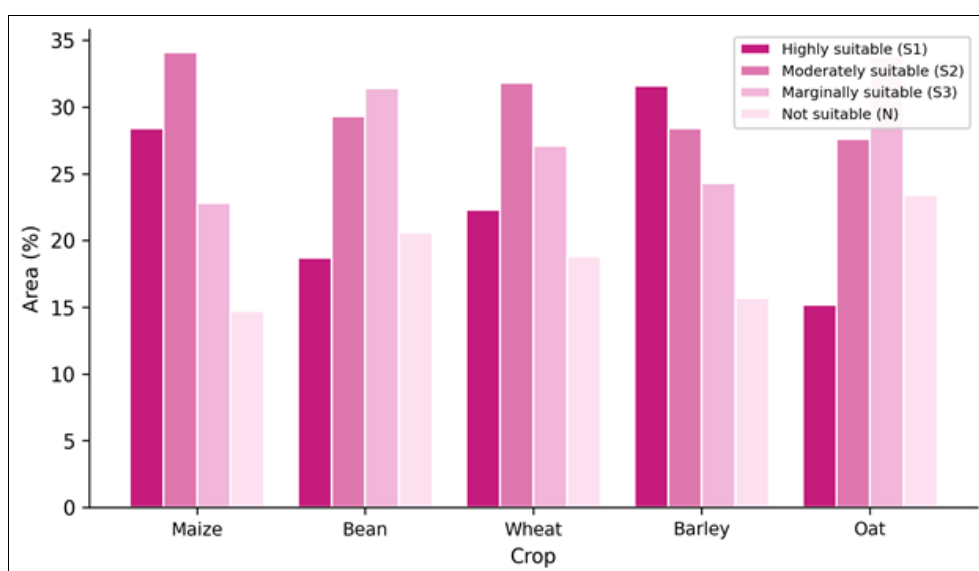


Fig 1: Suitability class distribution for five rainfed crops in the Puebla-Tlaxcala valley

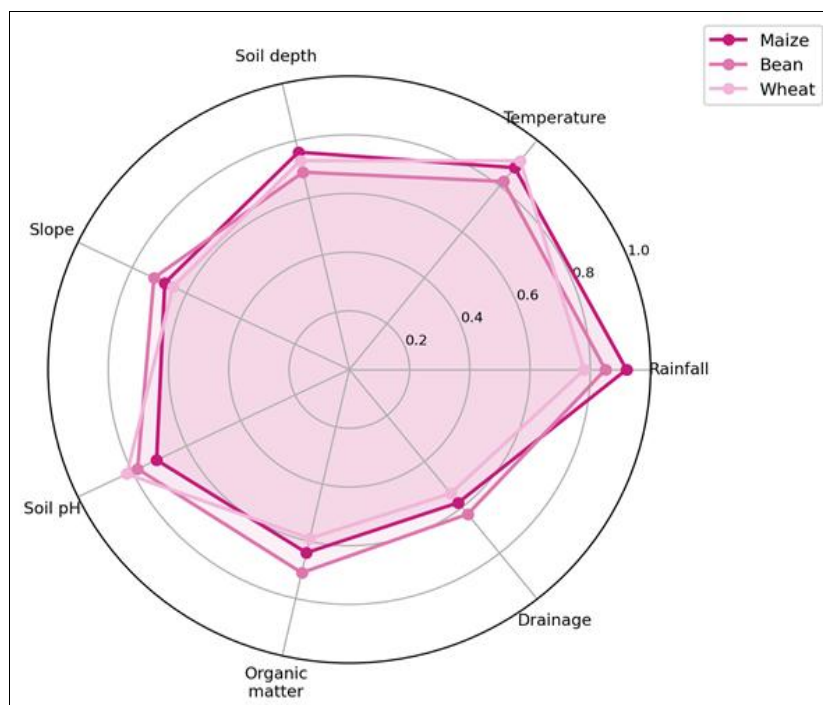


Fig 2: Radar chart of AHP factor weights for maize, bean, and wheat suitability evaluation

Comprehensive interpretation

Barley had the broadest highly suitable area (31.6%) due to its tolerance of shallow soils and moderate frost (Table 1, Figure 1). Maize ranked second (28.4% S1) but had the largest combined S1+S2 area (62.5%), reflecting its wide adaptation within the valley's elevation range. Bean showed the most restricted suitability (18.7% S1), limited by waterlogging sensitivity and narrow pH tolerance. Rainfall and temperature together accounted for 41–47% of the total weight across all crops (Table 2, Figure 2). Validation against INEGI land use data yielded 82.4% overall accuracy ($\kappa = 0.74$).

Discussion

The dominance of rainfall and temperature as suitability drivers at this elevation (2,100–2,800 m) is expected given the steep precipitation gradient across the valley and the frost risk at higher elevations [9]. The AHP weights were consistent with Akinci *et al.* [6] and Mendas and Delali [18], who also found climate factors accounting for 40–50% of total weight in semi-arid MCE studies. The 82.4% validation accuracy compares favorably with the 78–85% range reported for similar GIS suitability analyses [5, 17].

The maps identified approximately 340 km² where current maize cultivation falls in S3 or N classes, suggesting these areas might benefit from switching to barley or wheat. Conversely, about 210 km² classified as S1 for maize are currently planted to lower-value crops, representing an opportunity for intensification [8, 13].

Conclusion

GIS-based MCE with AHP weighting provided spatially explicit crop suitability maps for five rainfed crops in the Puebla-Tlaxcala valley. Barley and maize were the most broadly suitable crops, while bean and oat had the most restricted suitability. Rainfall and temperature were the dominant factors. The maps achieved 82.4% accuracy against observed land use. These outputs can support evidence-based crop allocation at the municipal level and identify zones where crop switching could improve productivity under existing climate conditions.

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