

COMPARATIVE ANALYSIS OF TECHNOLOGICAL AND AGRO–ECONOMIC PERFORMANCE OF SELECTED FIELD VEGETABLE CROPS IN ROMANIA

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Abstract: This study presents a comparative analysis of five economically important vegetable crops cultivated in Romania: field pepper (*Capsicum annuum*), field tomato (*Solanum lycopersicum*), common bean (*Phaseolus vulgaris*), potato (*Solanum tuberosum*), and onion (*Allium cepa*). The research evaluates both technological parameters (vegetation period, irrigation requirements, fertilizer doses, soil suitability, and rotation interval) and agro–economic indicators (implementation and maintenance costs, yield levels, irrigation impact, and market prices). Results show that tomato and pepper exhibit the highest yield potential under irrigated intensive systems, while potato and onion require significant fertilization due to high nutrient extraction rates. Common bean contributes agronomic benefits through biological nitrogen fixation, improving soil fertility and reducing subsequent nitrogen input requirements. The integration of these vegetable crops into diversified crop rotations enhances productivity, resource efficiency, and economic resilience under Romanian pedo–climatic conditions, aligning with EU CAP sustainability objectives.

Keywords: vegetable crops; agro–economic performance; irrigation efficiency; crop rotation; nutrient management

1. INTRODUCTION

Vegetable production represents one of the most intensive and economically dynamic sectors of Romanian agriculture. Compared with extensive cereal systems, vegetable crops require higher technological discipline, increased fertilization rates, strict plant protection programs, and regular irrigation. However, they also generate significantly higher added value per hectare and play a central role in domestic food security and rural employment (Ion, 2010).

Globally, agricultural systems face the dual challenge of increasing productivity while reducing environmental impact. Sustainable intensification approaches emphasize improving nitrogen-use efficiency, optimizing water management, and integrating legumes into rotations to enhance soil fertility (Tilman et al., 2011; Pretty & Bharucha, 2014). In this context, crop diversification is considered a key strategy for increasing resilience against climate variability and market volatility (Kazungu et al., 2023; FAO, 2022).

According to national statistical data, vegetable crops represent a significant share of Romania's horticultural production (INS, 2022).

Romania benefits from diverse pedo-climatic conditions, ranging from fertile chernozems in the southern plains to alluvial soils in river basins and sandy soils in Dobrogea. This diversity allows the cultivation of a wide range of horticultural crops under open-field conditions. Nevertheless, increasing climatic variability, characterized by more frequent droughts and irregular rainfall distribution, has intensified the need for improved irrigation efficiency and nutrient management strategies (Năescu & Alionte, 2008; El Chami & El Moujabber, 2024; Avgoustaki & Xydis, 2021).

Among the most representative field vegetable crops cultivated in Romania are field pepper (*Capsicum annuum*), field tomato (*Solanum lycopersicum*), common bean (*Phaseolus vulgaris*), potato (*Solanum tuberosum*), and onion (*Allium cepa*). These crops differ significantly in biological cycle duration, irrigation dependency, nutrient uptake patterns, and economic performance.

Tomato and pepper are high-value Solanaceae crops requiring intensive irrigation and fertilization management. Potato and onion are characterized by strong nutrient extraction and high sensitivity to soil fertility status. In contrast, common bean, as a leguminous crop, contributes to soil nitrogen enrichment through biological fixation, thereby reducing external nitrogen input requirements (Fageria, 2014; Pretty & Bharucha, 2014).

Under the framework of the EU Common Agricultural Policy (CAP) 2023–2027, increasing emphasis is placed on climate-smart agriculture, resource efficiency, and soil health restoration (European Commission, 2022). Therefore, understanding the comparative technological and agro-economic performance of major vegetable crops becomes essential for designing optimized crop rotations and sustainable production systems.

To better understand the complex interaction between agronomic, economic, and policy-related factors influencing vegetable production systems, a conceptual framework was developed. This framework synthesizes the main drivers affecting crop choice—such as climate variability, input costs, soil fertility status, and market demand—and links them to the expected agronomic and economic outcomes. The model integrates principles of sustainable intensification and resource-use efficiency (Tilman *et al.*, 2011; Pretty & Bharucha, 2014) and reflects the current orientation of the European Common Agricultural Policy toward climate-smart and resilient production systems (European Commission, 2022; El Chami & El Moujabber, 2024).

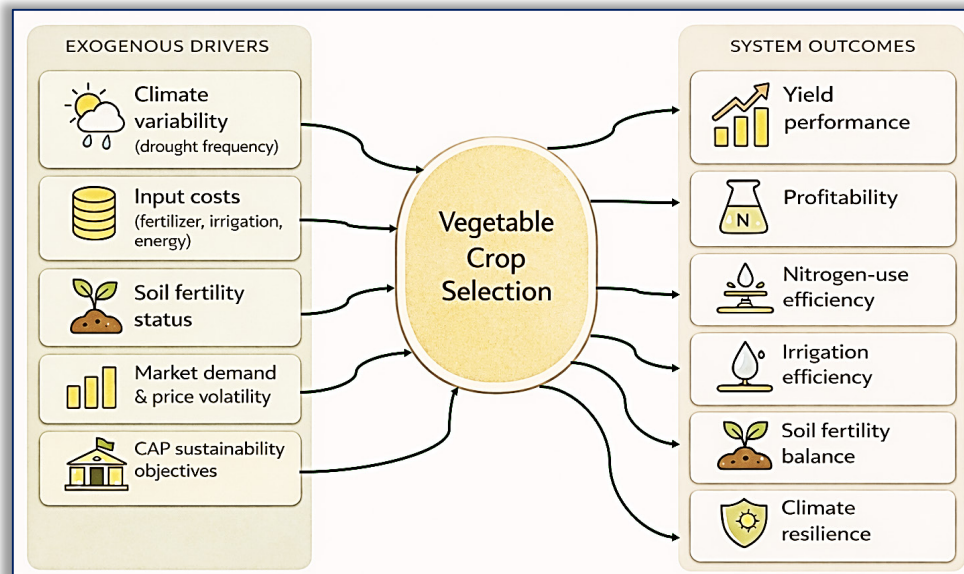


Figure 1 – Drivers and Outcomes of Vegetable Crop Selection under Romanian Conditions

The conceptual framework presented in Figure 1 illustrates the main drivers influencing vegetable crop selection and the expected agronomic and economic outcomes under Romanian production conditions.

The objective of this paper is to conduct a systematic comparative evaluation of five key field vegetable crops cultivated in Romania by integrating technological parameters (crop cycle, fertilization, irrigation requirements, soil suitability, rotation role) and agro-economic indicators (implementation cost, maintenance cost, yield performance, and irrigation responsiveness). The study aims to provide a decision-support framework for improving resource efficiency, economic stability, and resilience of vegetable production systems under Romanian conditions.

2. MATERIALS AND METHODS

The present study is based on a structured comparative assessment of five representative field vegetable crops cultivated in Romania: field pepper (*Capsicum annuum*), field tomato (*Solanum lycopersicum*), common bean (*Phaseolus vulgaris*), potato (*Solanum tuberosum*), and onion (*Allium cepa*).

■ Data Sources and Documentation

Technical and agronomic parameters were extracted from national crop technology sheets, official agronomic guidelines, and institutional reports, complemented by official statistical data from the Romanian National Institute of Statistics (INS), Ministry of Agriculture (MADR), Romanian Commodities Exchange (BRM), and National Agency for Fiscal Administration (ANAF) (MADR, 2024; BRM, 2024; ANAF, 2024).

The selected crops were chosen based on their economic relevance in Romanian horticulture, representativeness of different botanical families, differences in nutrient uptake patterns, variability in irrigation dependency, and contribution to crop rotation systems. To ensure systematic comparison, the evaluated indicators were grouped into two main categories:

■ Technological Parameters

The following agronomic characteristics were analysed:

- vegetation period (days from establishment to harvest);
- sowing/transplanting calendar;
- seasonal irrigation requirement (m³/ha);
- yield response to irrigation (%);

- fertilizer requirements (N, P₂O₅, K₂O expressed in kg active substance/ha);
- soil suitability and preferred soil texture;
- capacity to absorb residual nutrients from previous crops;
- nutrient contribution (N, P, K) left after harvest;
- recommended rotation interval (years).

Fertilizer requirements were expressed as active substance (kg s.a./ha) to ensure uniform comparison across crops and fertilization schemes.

Water requirements were standardized to cubic meters per hectare (m³/ha), and where irrigation norms were presented per application, total seasonal demand was calculated.

■ Agro-Economic Parameters

Economic performance was evaluated through:

- Implementation cost (RON/ha) divided by categories:
 - ≡ seedbed preparation;
 - ≡ planting/sowing;
 - ≡ seed or planting material;
- Maintenance cost (RON/ha) divided by categories:
 - ≡ fertilization;
 - ≡ plant protection treatments;
 - ≡ irrigation operations;
 - ≡ mechanical operations.
- Main yield (t/ha) under conventional systems
- Intensive yield potential (t/ha)
- Secondary biomass production (t/ha)
- Producer-level market price (RON/kg)

■ Data Normalization and Comparative Methodology

To allow direct comparison between crops with different biological characteristics and yield scales, the following normalization procedures were applied:

1. Costs were expressed uniformly in RON per hectare (RON/ha).
2. Yield was standardized in tons per hectare (t/ha).
3. Implementation cost per ton (RON/t) was calculated using:

$$\text{Cost per ton} = \frac{\text{Implementation cost (RON/ha)}}{\text{Average yield (t/ha)}}$$

4. Irrigation responsiveness was expressed as percentage yield increase compared to non-irrigated systems.

Mid-range values were used where cost or yield intervals were provided, ensuring representative average conditions rather than extreme performance values.

The comparative approach was descriptive-analytical, focusing on identifying structural differences between crops in terms of input intensity, resource use efficiency, economic risk profile, contribution to crop rotation sustainability.

The evaluation followed a systems-based perspective integrating biological performance, input-output balance, nutrient cycling dynamics, irrigation dependency, market orientation.

3. RESULTS

The results from determining the technological traits of the five crops studied are shown in Table 1.

Table 1. Technological traits comparison for the crops studied*

Crop	Vegetation Period (days)	Irrigation	Water Need (m ³ /ha)	N (kg/ha)	Rotation Interval
Pepper	120–150	Mandatory	4,000–5,000	120–180	3–4 years
Tomato	140–160	Mandatory	5,000–7,000	120–180	4–5 years
Bean	70–120	Recommended	3,500–5,000	20–40	3–4 years
Potato	90–130+	Mandatory	3,500–7,000	100–160	2–4 years
Onion	110–150	Mandatory	~900–1,000*	High (staged)	3–4 years

*Authors' synthesis based on Ion (2010), INS (2022), MADR (2024), and Pejić et al. (2011).

**per irrigation application; total seasonal higher

Common bean exhibits the shortest vegetation period (70–120 days), while tomato shows the longest cycle (up to 160 days including seedling stage). Pepper and onion require approximately 120–150 days, while potato varies depending on variety (90–130+ days).

All five crops respond positively to irrigation. Tomato presents the highest seasonal water demand (5,000-7,000 m³/ha), followed by pepper (4,000-5,000 m³/ha) and potato (3,500-7,000 m³/ha). Onion requires fewer irrigations but remains highly sensitive to soil moisture fluctuations. Bean requires moderate water supply but benefits significantly from irrigation during flowering and pod formation.

Yield increases under irrigation range between 30% (onion) and 70% (pepper and tomato), confirming strong irrigation responsiveness, particularly for onion where irrigation scheduling significantly influences productivity (Pejić *et al.*, 2011).

Nitrogen demand differs substantially among crops. Bean requires only 20-40 kg N/ha due to biological fixation. Pepper and tomato require 120-180 kg N/ha, while potato and onion exhibit high NPK demand due to tuber and bulb formation.

In terms of nutrient residual effects, it was found that bean leaves 20-40 kg N/ha available for subsequent crops, and pepper and tomato contribute moderate organic residues.

Potato and onion are considered heavy nutrient extractors and leave minimal nutrient bonuses, particularly under intensive fertilization regimes where phosphorus and potassium dynamics strongly influence soil nutrient balance (Zhang *et al.*, 2008).

All crops prefer fertile, well-drained soils (chernozems, alluvial soils, loamy or sandy-loam textures). Solanaceae crops (pepper, tomato, potato) require rotation intervals of 3-5 years to reduce disease pressure. Bean and onion also require 3-4 year intervals to prevent soil-borne pathogen accumulation. Beyond technological characteristics, the economic dimension plays a decisive role in crop selection and farm-level management decisions.

Therefore, some of the main agro-economic indicators were comparatively analysed for the five selected vegetable crops. These indicators provide an integrated perspective on production intensity, input dependency, and potential economic performance under Romanian open-field conditions. The results are presented in Table 2.

Table 2. Agro-economic traits comparison for the five crops studied*

Crop	Implementation (RON/ha)	Maintenance (RON/ha)	Average yield t/ha	Possible yield Increase due to irrigation (%)
Pepper	7,000–9,500	6,500–8,500	20–25	50–70
Tomato	5,800–7,900	4,500–7,000	25–35	40–70
Bean	1,200–1,600	1,500–2,200	1.6–1.8	40–70
Potato	~3,100–3,800 (+seeds)	2,600–4,000	14–17	30–55
Onion	2,100–3,050	1,600–2,300	11–15	30–60

*Data compiled and processed by the authors based on national statistical reports and institutional technical guidelines (INS, 2022; MADR, 2024; BRM, 2024; ANAF, 2024).

Implementation and maintenance costs vary considerably among the five crops.

Pepper shows the highest implementation cost (7,000-9,500 RON/ha), followed by tomato (5,800-7,900 RON/ha). Potato and onion present moderate implementation costs, while bean exhibits the lowest cost (1,200-1,600 RON/ha).

Maintenance costs follow a similar pattern, with pepper and tomato requiring multiple fertilization stages and plant protection treatments. Bean remains the least input-intensive crop.

Market prices vary significantly. Dry bean exhibits relatively high price stability (~5 RON/kg), while potato and onion present lower per-unit prices but stable market demand. Pepper and tomato achieve high retail prices but depend strongly on quality and market channel.

The combined technological and economic assessment confirms complementary functional roles of the analysed species within diversified vegetable rotations.

Tomato and pepper represent high-value intensive crops characterized by long vegetation cycles, high NPK demand, strong irrigation dependency, elevated plant protection requirements. Their economic viability is directly linked to market access and irrigation infrastructure availability.

Potato and onion function as high nutrient-extraction crops. Their shallow root systems and bulb/tuber formation result in significant potassium and nitrogen uptake, necessitating structured fertilization plans. Long-term soil fertility preservation requires balanced fertilization and the integration of organic amendments, which have been shown to improve nutrient retention and soil structure (Diacono & Montemurro, 2010).

Common bean introduces an ecological balancing component into the rotation. Through symbiotic nitrogen fixation, it reduces external nitrogen input requirements and contributes 20-40 kg N/ha

to subsequent crops. This role is particularly relevant under EU policies encouraging reduction of synthetic fertilizer use.

From a systems perspective, integrating legumes with *Solanaceae* and bulb crops improves nutrient cycling efficiency, soil organic matter balance, disease pressure reduction, and economic risk distribution. Such diversified systems are more resilient to climatic variability and input price fluctuations (Tilman *et al.*, 2011; Kazungu *et al.*, 2023).

The graphical representations (Figures 2-4) illustrate yield differences, cost efficiency per ton of production, and irrigation sensitivity. These indicators were selected due to their integration of both technological and economic performance, allowing holistic evaluation of production sustainability.

In Figure 2, the comparative average yield per hectare is illustrated. The findings confirm that tomato achieves the highest biological productivity under Romanian open-field conditions, followed by pepper. Potato and onion show moderate yield levels, while dry bean presents lower volumetric yield but higher protein concentration and rotational value.

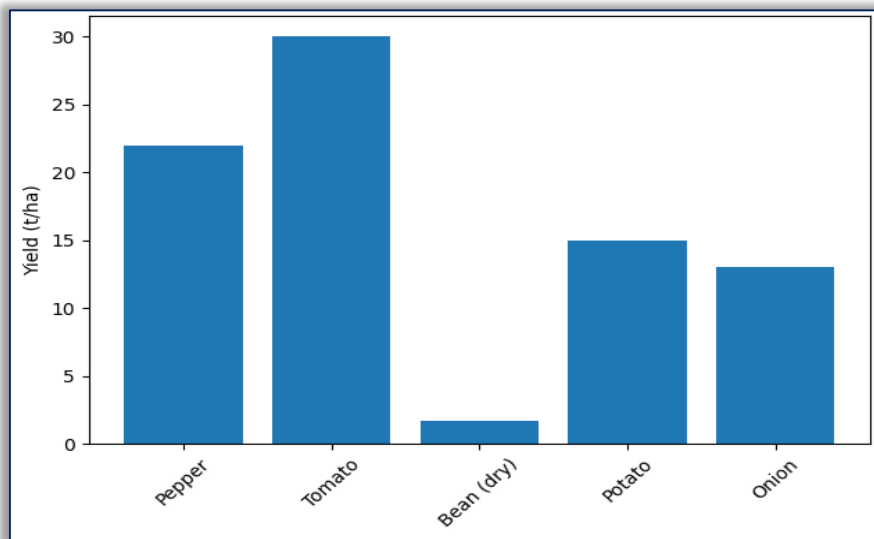


Figure 2 – Average Yield per Hectare

The results indicate that fruit-forming vegetables (tomato and pepper) are biologically more productive per hectare compared to grain legumes and bulb crops, but their performance is strongly dependent on irrigation and fertilization intensity.

Figure 3 presents the implementation cost per ton of production. The analysis highlights that common bean exhibits the highest cost per ton due to its relatively low yield despite low implementation costs. Tomato and onion show better cost distribution per unit of production under intensive systems, while pepper remains intermediate due to higher establishment investment.

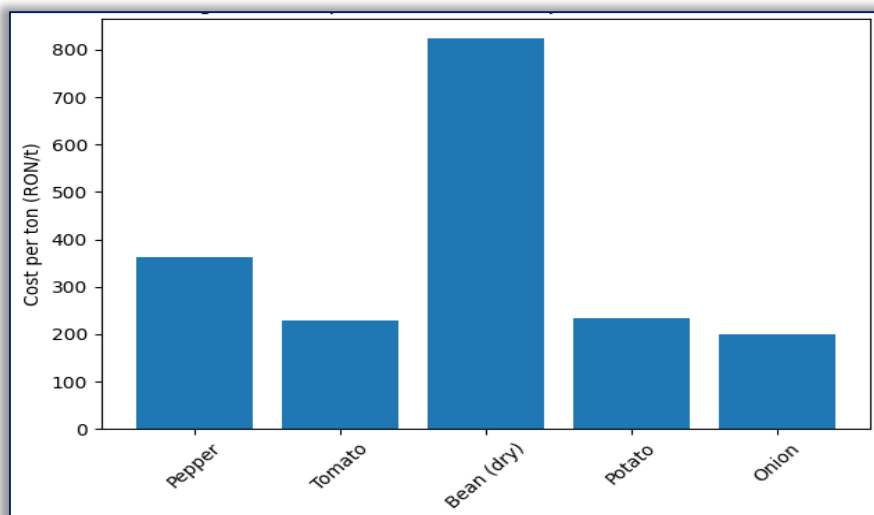


Figure 3 – Implementation Cost per Ton of Production

This indicator is particularly relevant for farm-level profitability assessments, as cost per ton integrates both biological performance and input investment.

Figure 4 illustrates irrigation responsiveness. Pepper shows the highest irrigation sensitivity (up to 60% yield increase), followed closely by tomato and bean. Onion exhibits the lowest but still significant irrigation response.

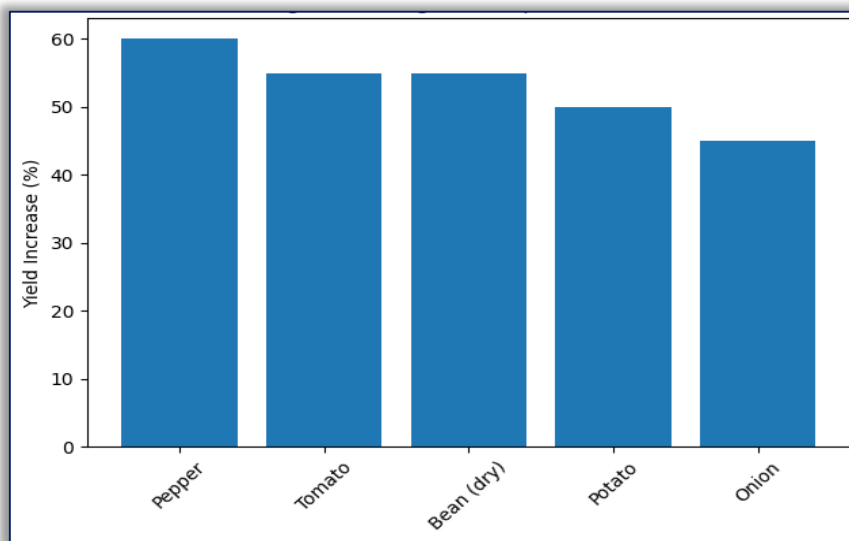


Figure 4 – Irrigation Impact on Yield

These findings confirm that vegetable crops are among the most water-dependent agricultural systems and require optimized irrigation strategies to maintain yield stability under increasing drought frequency. (Snyder & Melo-Abreu, 2005).

4. CONCLUSIONS

This comparative assessment demonstrates that significant structural differences exist among the five analysed vegetable crops in terms of technological requirements, input intensity, and economic performance.

Tomato and pepper show the highest biological productivity and strong responsiveness to irrigation, confirming their suitability for intensive systems with adequate water and nutrient management. However, their high implementation and maintenance costs indicate increased economic exposure to input price fluctuations and water availability constraints.

Potato and onion are characterized by substantial nutrient extraction, particularly nitrogen and potassium, and require carefully structured fertilization strategies to prevent long-term soil depletion. Their moderate yield levels and stable market demand make them economically viable when integrated within balanced rotations.

Common bean plays a strategic agronomic role due to its low nitrogen requirement and capacity for biological nitrogen fixation, contributing to soil fertility improvement and reduced external fertilizer dependency. Its inclusion in vegetable rotations enhances nutrient cycling efficiency and supports sustainable intensification strategies.

The evaluation of yield performance, cost per ton, and irrigation responsiveness confirms that vegetable production systems are highly input-sensitive and strongly dependent on optimized water management. Irrigation responsiveness ranging between 30-70% highlights the central role of irrigation infrastructure in ensuring production stability under increasing climatic variability.

Overall, diversified rotations combining high-value Solanaceae crops with legumes and moderate nutrient extractors improve resource-use efficiency, reduce agronomic risk, and enhance economic resilience. Such systems are consistent with the objectives of the EU Common Agricultural Policy 2023-2027, promoting climate-adaptive agriculture, efficient nutrient management, and long-term soil health preservation. Therefore, the results of this study provide a comparative decision-support framework for vegetable producers and policymakers seeking to optimize crop selection, rotation design, and resource allocation under Romanian pedo-climatic conditions.

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