

Reducing Chemical Inputs in Vegetable Cropping Systems through Integrated Pest Management: A Comparative Analysis of Morocco and North Africa

*Dalal Boudoudou*¹ [0009-0004-3734-7486], *Khadija El-Moustaqim*² [0009-0007-9193-6638], *Mounir Boutarbouch*¹, *Aziza Lamchamech*¹, *Ayoub Ghailane*³, and *Jamal Mabrouki*³ [0000-0002-3841-7755]

¹ Ibn Tofail University, Faculty of Sciences, Laboratory of Plant, Animal and Agro-Industrial Production, Kénitra, Morocco.

²Improvement and Valuation of Plant Resources, Faculty of Sciences, Ibn Tofail University—KENITRA-University Campus, Kenitra 14000, Morocco

³Laboratory of Spectroscopy, Molecular Modelling, Materials, Nanomaterials, Water and Environment, CERN2D, Mohammed V University in Rabat, Faculty of Science, AV Ibn Battouta, Agdal, Rabat 10106, Morocco.

Abstract. For North African countries, the production of vegetables is essential for food security, as well as for the agricultural economy of these nations; however, vegetable production in this region is threatened by the excessive use of chemicals in agricultural practise. The trends of mineral nitrogen and phosphorus loss and nutrient use efficiency (NUE) are examined in North African countries (Morocco, Tunisia, Algeria and Egypt), with Morocco as the primary example, between 2019-2023. The analysed results show the annual variability of fertiliser input reflects the extent to which farmers have adapted their fertilising methods and the agricultural intensification of their respective countries. Egypt uses the most nitrogen and phosphorus fertiliser compared to other North African countries and this reflects Egypt's high degree of agricultural intensification and irrigated agriculture, while Tunisia and Algeria use significantly lower amounts of nitrogen and phosphorus in their fertiliser due to their more extensive and less intensively farmed systems. Morocco holds an intermediate position, characterized by moderate inputs combined with good nitrogen-use efficiencies. These trends may indicate a gradual rationalisation of fertilization practices in Morocco, which is enabled by the growing integration of integrated pest management (IPM) and biological control measures. In general, this research emphasizes the potential of IPM-based strategies to reduce chemical dependence and sustain productivity. In particular, it identifies Morocco as a potentially interesting case for sustainable intensification of vegetable production systems in North Africa.

1 Introduction

Vegetable growing is a strategic component of North African agricultural systems due to its importance in food security (and dietary diversification) and job creation in rural and peri-urban areas [1,2]. In Morocco (as in Tunisia, Algeria, and Egypt), vegetables are an

important source of farm income and in many cases a contributor to agro-food exports [3]. The irrigation expansion and planting practices of intensive cropping systems have facilitated increases in yields, but were also accompanied by increasing dependence on chemical inputs (Endale et al.

This amplification has been associated with higher application of mineral fertilizers and pesticides to maintain yields and pest population control, respectively. In Morocco and other countries of the region, a number of researches have also indicated excessive input use as well as the predominance of conventional management in vegetable production [4,5,6]. In Egypt, the very intensive irrigated systems in the Nile Valley and Delta are heavily dependent on large quantities of fertilizers, leading to high nutrient surpluses and environmental impacts [1,7].

Chemical inputs have deepened the concern about environmental and health effects, such as soil and water contamination, nutrient saturation and biodiversity depletion [8,9]. Organic control and IPM. In this context, biological control and integrated pest management (IPM) are considered as the most valuable strategies for reducing pesticide utilisation and system efficiency. IPM systems go further in rationalizing fertilization by stimulating the health of the crops, thus reducing yield losses due to stress and increasing nutrient uptake efficiency [10,11].

Against this backdrop, the current study is proposed to analyze trends of temporal evolution of mineral nitrogen and phosphorus inputs and of nitrogen-use efficiency in vegetable production systems and particularly weeding well a focal country as Morocco has made an update since 2009–2013 [12], while in Tunisia, Algeria and Egypt which is allowed during the period from 2019 to 2023. This comparative analysis seeks to determine regional disparities and to evaluate the IPM-based strategies' potential as an accelerator for facilitating a sustainable transformation of vegetable farming systems in North Africa.

2 Principles of Activated Sludge Systems' Nutrient Removal

2.1 Study area and data sources

This paper is concentrated on vegetable production systems in North Africa, with Morocco as the main case study, and the analysis was complemented by Tunisia, Algeria and Egypt for comparison. The study draws on the FAOSTAT cropland nutrient budget database that aggregates and harmonizes national level indicators with mineral fertilizer use and nutrient management as its variables [3,12]. The analysis includes data for 2019–2023, which provides an opportunity to analyze recent developments in fertilization preferences.

2.2 Indicators and data processing

The chosen indicators are the mineral N inputs (kg N ha^{-1}), P inputs per hectare (kg P ha^{-1}) and nitrogen-use efficiency (%) as which directly depend on fertilization intensity, environmental pressure and sustainability in vegetable cropping systems. Data were processed and analysed in Python [12] using libraries specifically designed for data manipulation and graphical visualisation. Values for each year were averaged by country, to compare inter-countries.

2.3 Comparative approach

They took a descriptive and comparative approach with bar-chart visualizations to allow for easy comparison between countries. Results were interpreted in relation to the degree of

agricultural intensification and increasingly widespread use of IPM and biological control strategies, as reported in the relevant scientific literature. Such a methodology allowed, for the first time, to highlight regional differences and to "locate" Morocco in relation to other North African countries with respect to nutrient management as well as sustainability of the vegetable production systems.

3 Results and discussion

Input of mineral nitrogen per hectare showed notable inter-annuality between 2019 to 2023: It increases from 2019, decreases distinctly in 2021 and tends gradually to rise again. This temporal change is indicative of adaptive nitrogen fertilization practices according to agronomic limitations and changing environmental conditions. Comparable results were observed in intensive and irrigated cropping systems in Morocco, where an increase on nitrogen use efficiency was linked with a better matching between the amount of N supplied and that taken up by crop [5,4]. The drop observed in 2021 may thus reflect an improved nitrogen management that could be viewed as being related to a gradual implementation of integrated pest management (IPM) and rational use of fertilizers at national level [13,14].

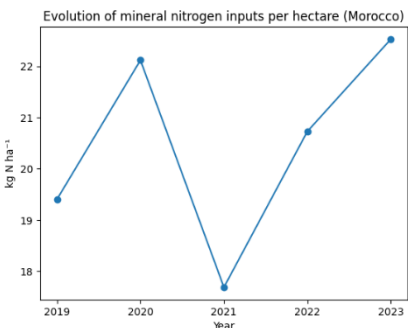


Figure 1: Evolution of mineral nitrogen inputs per hectare in Morocco (kg N ha⁻¹).

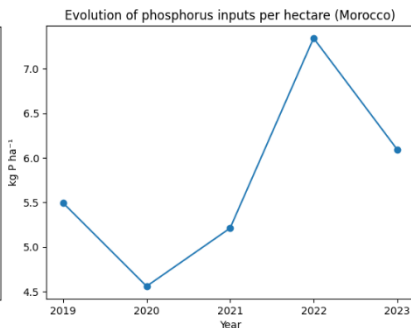


Figure 2: Evolution of phosphorus inputs per hectare in Morocco (kg P ha⁻¹).

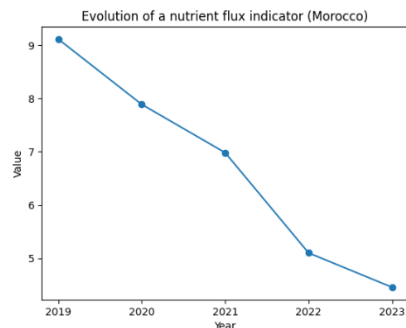


Figure 3: Evolution of a nutrient flux indicator in Morocco.

Phosphorus inputs (kg P ha⁻¹) per hectare had different trajectories and declined from 2019 to 2020, thereafter increased year on year until a peak in 2022 after which it decreased slightly in 2023. Given the low mobility of P in soils and its accumulation under high fertilization, these patterns underline the necessity for better management of phosphorus in Moroccan agro-ecosystems. Coping with an Accumulation of Phosphorus Under Mediterranean and Moroccan Conditions Earlier workers worked under Mediterranean and Moroccan conditions have shown that integrated nutrient management (INM) approach could ameliorate phosphorus accumulation while sustaining crop productivity [15,16]. Recent data on phosphorus input levels support our previous work and demonstrate growing recognition for environment-friendly fertilizing techniques associated with Integrated Pestmanagement (IPM) practices [17].

However, in contrast, use of the Nutrient Flow Indicator displayed long-term, continued, and widespread integrated reduction in the total value of nutrient inputs from all Yasuní Community Territory farming areas. Extreme Fact, the overall values of Nutrient Flow Indicator have decreased due directly to the pressure on cropping systems from nutrients originating from soil. This is the worst telltale of leaning towards further integration. This perception can be interpreted by the concomitant positive effect of new management systems

including bio control methods and the spreading of LPI treatments, in Moroccan vegetable production systems [18,19]. In general, the results in this study indicate that IPM not only increases pesticide use efficiencies but also the overall input use efficiency, seen as a path towards an environmentally-based sustainability of Moroccan vegetable farming enterprises and [20,1]

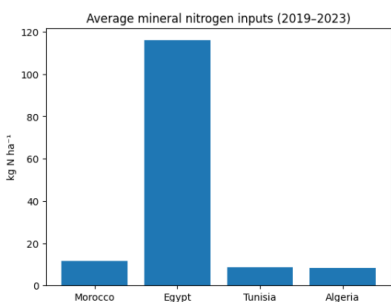


Figure 4: Comparison of Average Mineral Nitrogen Inputs in Vegetable Cropping Systems (2019–2023)

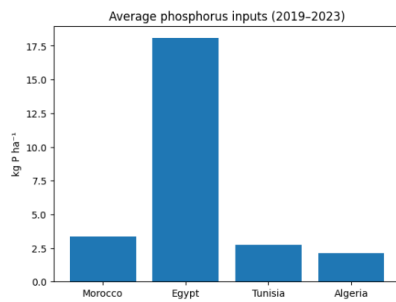


Figure 5: Comparison of Average Phosphorus Inputs in Vegetable Cropping Systems (2019–2023)

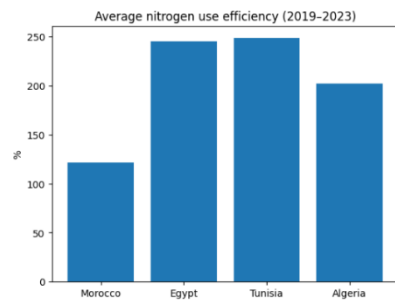


Figure 6: Comparison of Average Nitrogen Use Efficiency in Vegetable Cropping Systems (2019–2023)

The comparison of hectare-based mineral nitrogen inputs between 2019 and 2023 clearly shows the different fertilisation intensity among the four countries. It shows predecessors value such as nitrogen input significantly higher in Egypt than the three other countries (Morocco, Tunisia and Algeria), demonstrating the very intensive character of its irrigated agricultural productions, notably in Nile Valley where productivity goals heavily depend on mineral fertilization [1,21]. In contrast, in Tunisia and Algeria -and to a lesser extent in Morocco- nitrogen input is lower; this can be attributed mainly to the use of more extensive systems and structural constraints that restrict the use of N fertilizers [22,23]. Morocco lies between them, indicating a rationale for fertilization based on equilibrium as fertilizer optimization became a target that focused on productivity goals alongside the emergent policy to rationalize nitrogen application by enhanced nutrient balance at field level [5,4].

Phosphorus entry is following the same trend, but Egypt is highest at the input level increasing risk of P accumulation and the associated environmental damage. In Morocco there are medium rates of phosphorus use (higher than in Tunisia and Algeria) but much lower levels compared with Egypt. This is consistent with emerging national interventions focused on soil testing, balanced fertilization and integrated nutrient management (INM) in high value crops [15,24]. Tunisia and Algeria also indicate lower input of phosphorus, thereby decreasing environmental pressure but possibly limiting productivity in P-deficient soils if not adequately replaced [25,26].

They are also distinguished by NUE (neutral nitrogen yield). Even though Egypt has a high relative yield, this is achieved with an extremely high level of nitrogen input in fact likely not long reaching environmental inefficiency [27]. Morocco has a medium to high NUE, and so low entry is likely to be a more compromise. This profile has implications, e.g. Morocco is probably highly activated by accessing more aid for appropriate use and bio-control which can help in higher crop productivity as opposed to the effect on density of chemical application [28]. The entire elements of this comparative study place Morocco as an intermediate country, but with many possibilities to take advantage of the increased

integration between IPM and rational fertilization for the sustainability of vegetable cropping system intensification in North Africa.

4 Conclusion

As a whole, this study illustrates that supply and demand of nutrient management practices differ greatly through time and space according to differences in production systems and extent of agricultural intensification. Supplies of mineral N and P exhibited strong inter-annual variability that ranged from 2019 to 2023 due to the adoption of adaptive fertilization methods, introduction of threshold-based nutrient management systems and influence of co-factors like livestock production and temporary transfers in nutrient soil.

Concurrently, release of information-bearing signaling molecules was correlated with an appreciable loss in fertilization pressure. Our results highlight that crop systems in transition towards IPM and biological control have received combined regulatory impact, where optimized fertilization contributes to improved nutrient use efficiency and overall system stability.

Egypt has continued to have high regional nitrogen and phosphorus input levels because its major cropping systems are focused on intensive irrigation production systems. In relation to nitrogen and phosphorus use, intensive crop production will produce high crop yields; however, the intensive nature of this system creates a higher-risk situation for environmental degradation. Tunisia and Algeria are examples of countries with a much lower level of use of nitrogen and phosphorus, thereby reducing the potential for environmental degradation, but the potential for low yields when nutrients become competitive for crop production is a concern.

Morocco sits between two extremes and serves as a case study of an example of a moderate input to high NUE solution for improving food production while using fewer chemicals. Between these two extremes, Morocco represents a middle ground where moderate application of inputs can produce relatively high NUE. This balance creates an opportunity for Morocco to develop the capacity to move towards sustainable intensification through the use of IPM-based methodologies and integrated crop nutrient management practices. The development of these two areas of agriculture would facilitate Morocco's efforts to reduce the amount of chemical fertilizers used in agriculture while ensuring the continued productivity of crops in this region of the world, thus providing a valid example of the movement toward sustainable tools for sustainable agricultural systems in North Africa.

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