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ASSESSMENT OF THE IMPACT OF MINERAL FERTILIZER USE ON THE ECOLOGICAL CONDITION OF SOIL AND WATER RESOURCES AND IMPROVEMENT OF MITIGATION METHODS

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Abstract. Mineral fertilizers sustain crop productivity but inappropriate nutrient application can increase nitrate leaching, phosphorus runoff, soil acidification and indirect greenhouse-gas emissions. This thesis synthesizes international literature and proposes an integrated assessment and mitigation framework connecting soil testing, nutrient budgeting, hydrological monitoring and site-specific fertilizer decisions. Indicators, equations and a scenario-based comparison illustrate how nutrient use efficiency and exposure pathways may be evaluated. The graphical risk scores are explicitly hypothetical and are not measured field results. The analysis identifies balanced application, split dosing, buffer strips, irrigation control and soil-health management as complementary measures for protecting soil and water resources.

Keywords: mineral fertilizers; nitrate leaching; phosphorus runoff; soil quality; water pollution; nutrient use efficiency; sustainable agriculture; risk assessment.

INTRODUCTION

Nitrogen (N), phosphorus (P) and potassium (K) fertilizers support the food supply by replacing nutrients removed in harvested biomass. However, nitrogen surpluses can produce mobile nitrate (NO_3^-), while phosphorus transported with eroded particles and runoff can accelerate freshwater eutrophication. Reactive nitrogen is also linked to air pollution and nitrous oxide formation [1–3]. The environmental effect of a fertilizer dose depends on crop demand, soil texture, rainfall or irrigation timing, fertilizer formulation and drainage connectivity rather than fertilizer quantity alone [4, 5].

The aim of this thesis is to develop a literature-based framework for evaluating fertilizer-related ecological pressures on soil and water and to identify a practical hierarchy of mitigation strategies. The work is a conceptual synthesis; no original soil or water samples were collected.

MAIN PART

1. Exposure mechanisms and ecological indicators

The principal transfer routes are nitrate leaching below the root zone, dissolved or particulate phosphorus loss in surface runoff, ammonia volatilization and microbial transformation of reactive nitrogen. Nitrification ($NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$) and denitrification ($NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$) help explain why soil aeration and moisture regulate risk [2, 6]. Repeated ammonium-based fertilization may contribute to acidification, particularly when base-cation losses are not corrected. Soil pH, electrical conductivity, organic carbon and available nutrients should therefore be interpreted with nitrate and phosphate measurements in nearby water [4, 7].

A simplified annual field nitrogen balance can be expressed as: N_surplus = N_fertilizer + N_manure + N_deposition + N_fixation − N_harvest − ΔN_soil. An operational nitrogen use efficiency indicator is NUE (%) = (N_harvest / N_inputs) × 100. Both metrics require consistent system boundaries and should not be treated as direct measurements of water contamination [3, 8].

For drainage monitoring, nutrient export may be estimated as Load (kg) = Σ [C_i (mg L^{-1}) × Q_i (m^3) × 10^{-3}], where C_i is the concentration and Q_i the water volume over interval i. Seasonal sampling and flow-weighted measurements are necessary to capture episodic losses [5, 9].

2. Integrated methods for assessment and risk reduction

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The proposed assessment combines: (i) baseline soil fertility mapping and irrigation-water testing; (ii) seasonal documentation of fertilizer source, rate, timing and placement; (iii) monitoring of nitrate, orthophosphate, pH, EC and sediment at drainage points; and (iv) yield-normalized nutrient balance calculations. Interpretation should account for local hydrology and comparison fields or pre-intervention baselines, because a concentration alone cannot attribute pollution to fertilizer [3, 5].

Table 1. Proposed monitoring indicators and management responses

Indicator / pathway	Evidence of concern	Priority response
Soil pH and EC	Acidification or salinity trend	Lime only if tests justify; balance nutrient sources
Soil mineral N and N surplus	Residual nitrate / repeated input excess	Soil-test-based rates; split N applications
Drainage NO_3^-	Elevated concentrations or seasonal loads	Match timing to uptake; adjust irrigation
Runoff P and sediment	P peaks after storms; eroded particles	Buffer strips, erosion control, P placement
Crop N uptake and yield	Low recovery relative to N supplied	Targeted placement and site-specific dosing

Mitigation should follow the "right source, right rate, right time, right place" principle, supported by crop rotation, cover crops, controlled irrigation and riparian buffers. Fertilizer inhibitors or enhanced-efficiency products may be useful under suitable local conditions but their performance should be evaluated against cost, crop yield and measured losses [3, 8, 10].

3. Scenario analysis and interpretation

To visualize the expected direction of change, four hypothetical management scenarios were assigned relative risk indices, with conventional application normalized to 100. Lower indices represent assumed reductions in combined nutrient-loss exposure; they are illustrative teaching values, not empirical effect sizes or meta-analytic estimates. The chart is therefore useful only for explaining the proposed monitoring approach.

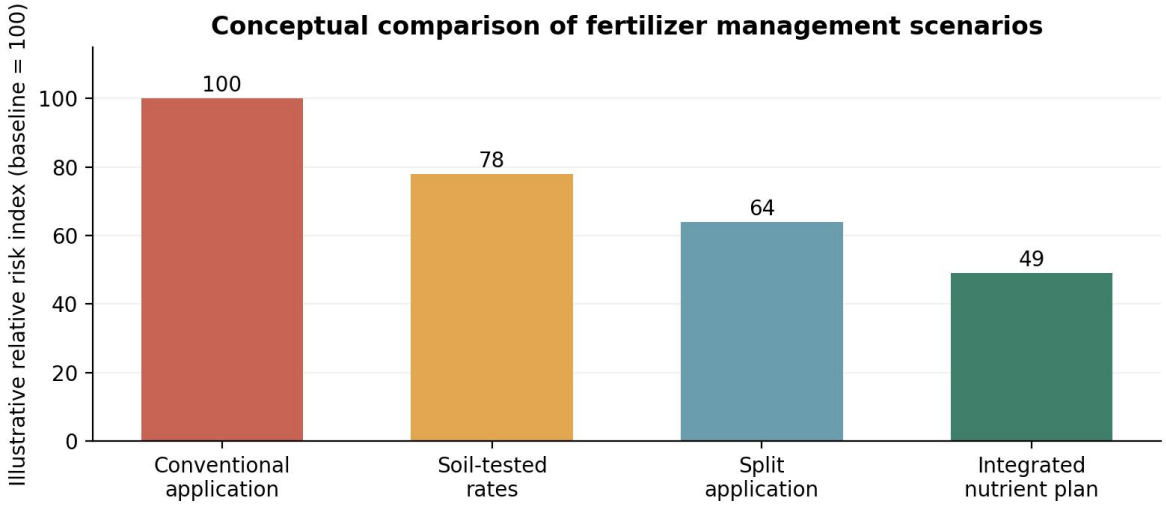


Figure 1. Illustrative scenario scores (hypothetical values; no field measurements).

The scores in Figure 1 do not establish that any practice will reduce nitrate or phosphate loss by a specific percentage. Actual performance should be tested using replicated field plots or paired watersheds across seasons, with uncertainty intervals and hydrologic covariates. Relevant outcome

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measures are kg N or P lost per hectare, concentrations during drainage events, changes in soil health and marketable yield [4, 9].

CONCLUSION

Mineral fertilizer use should be evaluated through both agricultural benefits and measurable nutrient pathways affecting soil and water. A combined system of soil analysis, input–output nutrient balances, water-quality surveillance and crop performance assessment offers a stronger basis for decisions than application-rate targets alone. The recommended improvements are calibrated nutrient doses, split applications, improved irrigation scheduling, phosphorus-loss controls and periodic reassessment of soil chemistry. Future field validation should quantify nutrient export, yield, costs and uncertainty before claims of environmental effectiveness are made.

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