

NUTRIENT GOVERNANCE FOR AGRO-ECOLOGICAL TRANSITION UNDER FLORIDA'S STATEWIDE BMP PROGRAM

GOUVERNANCE DES NUTRIMENTS POUR LA TRANSITION AGRO- ÉCOLOGIQUE DANS LE CADRE DU PROGRAMME DE MEILLEURES PRATIQUES DE GESTION (BMP) DE L'ÉTAT DE FLORIDE

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ABSTRACT

Agro-ecological transition in irrigated agricultural systems increasingly depends on institutional capacity to translate diverse and evolving scientific evidence into timely, accountable management decisions. This paper examines the University of Florida Institute of Food and Agricultural Sciences (UF/IFAS) Nutrient Management Program as a legislatively mandated, nutrient governance framework that supports agro-ecological transition through Florida's statewide agricultural Best Management Practices (BMP) program administered by the Florida Department of Agriculture and Consumer Services (FDACS) Office of Agricultural Water Policy (OAWP).

Florida's agricultural BMP program is the primary statewide mechanism for reducing nutrient and water impacts from agriculture while maintaining economic viability. Nutrient application rate recommendations developed by UF/IFAS function as the scientific foundation for nutrient BMPs and play a central role in the effectiveness and credibility of the statewide program. Beginning in 2021, the Florida Legislature directed UF/IFAS to evaluate fertilizer application rates, develop nutrient recommendations, and advance site-specific nutrient management across multiple cropping systems and regions, with biannual reporting requirements to legislative leadership.

Rather than presenting crop-specific fertilizer response results, this paper focuses on the institutional architecture developed to meet legislative mandates while aligning scientific outputs with the operational needs of the FDACS OAWP BMP program. The paper emphasizes adaptive governance, data integration, iterative recommendation development, and the linkage between nutrient recommendations and irrigation-driven nutrient transport processes. A case example involving revised phosphorus recommendations illustrates how interim guidance was developed under uncertainty while maintaining accountability to producers, policymakers, and water quality objectives.

The Florida case demonstrates that agro-ecological transition at territorial scales depends not only on agronomic or technological innovation, but on governance systems capable of aligning science, public policy, irrigation management, and on-farm decision making. The governance mechanisms described here offer transferable insights for regions seeking to operationalize nutrient and water management science within complex regulatory and production environments.

Keywords: Agro-ecological transition; economic viability; data integration; water quality; water management.

RESUME

La transition agroécologique dans les systèmes agricoles irrigués dépend de plus en plus de la capacité institutionnelle à traduire des preuves scientifiques diverses et évolutives en décisions de gestion opportunes et responsables. Cet article étudie le programme de gestion des nutriments de l'Institut des sciences alimentaires et agricoles (UF/IFAS) de l'Université de Floride en tant que cadre de

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gouvernance des nutriments d'ordre législatif. qui soutient la transition agro-écologique grâce aux meilleures pratiques de gestion agricole (BMP) de l'État de Floride, programme administré par le Bureau de la politique des eaux agricoles (OAWP) du Département de l'agriculture et des services aux consommateurs de la Floride (FDACS).

Le programme agricole BMP de la Floride est le principal mécanisme à l'échelle de l'État, chargé de réduire les impacts des nutriments et de l'eau de l'agriculture tout en maintenant la viabilité économique. Les recommandations de l'UF/IFAS relatives au taux d'application des nutriments servent d'une base scientifique aux BMP relatives aux nutriments et jouent un rôle central dans l'efficacité et la crédibilité du programme à l'échelle de l'État. À partir de 2021, la législature de la Floride a chargé l'UF/IFAS d'évaluer les taux d'application des engrais, d'élaborer des recommandations en matière de nutriments et de faire progresser la gestion des nutriments adaptée aux spécificités de chaque site dans plusieurs systèmes de culture et régions, avec des exigences de rapport semestriel aux responsables législatifs.

Plutôt que de présenter des résultats spécifiques à certaines cultures concernant la réponse aux engrais, cet article met l'accent sur l'architecture institutionnelle mise en place pour répondre aux exigences législatives, tout en alignant les résultats scientifiques avec les besoins opérationnels du programme BMP du FDACS-OAWP. L'article met l'accent sur la gouvernance adaptative, l'intégration des données, le développement itératif de recommandations et le lien entre les recommandations faites concernant les nutriments et les processus de transport des nutriments induits par l'irrigation. Une étude de cas portant sur la révision des recommandations relatives au phosphore illustre la manière dont des directives provisoires ont été mises en place dans un contexte d'incertitude, tout en garantissant la responsabilité envers les producteurs et les décideurs politiques tout en respectant des objectifs de qualité de l'eau.

Le cas de la Floride démontre que la transition agro-écologique aux échelles territoriales dépend non seulement de l'innovation agronomique ou technologique, mais aussi de systèmes de gouvernance capables d'harmoniser la science, les politiques publiques, la gestion de l'irrigation et la prise de décision au niveau des exploitations. Les mécanismes de gouvernance décrits ici offrent des perspectives transférables aux régions recherchant à opérationnaliser la science de la gestion des nutriments et de l'eau au sein d'environnements réglementaires et de production complexes.

Mots-clés : Transition agroécologique; Viabilité économique; Intégration des données; Qualité de l'eau; Gestion de l'eau.

1. INTRODUCTION

Agro-ecological transition in irrigated agricultural systems is increasingly shaped not only by biophysical constraints, but also by governance structures that require scientific decisions to be made under fixed policy timelines. Nutrient management occupies a critical space at the intersection of agricultural productivity, water quality protection, and public accountability. While advances in fertilizer technologies, soil diagnostics, and modeling tools have improved the technical basis for nutrient recommendations, the institutional challenge of translating heterogeneous scientific evidence into timely and defensible management guidance remains under-examined. Traditional nutrient management research has focused primarily on crop-specific fertilizer response functions derived from multi-year field trials. Although these approaches remain essential, they often operate on timelines misaligned with legislative and regulatory demands for action. In many jurisdictions, public agencies are required to provide Best Management Practices (BMPs) and nutrient guidance before long-term experimental certainty can be achieved. This creates a need for governance frameworks capable of integrating evolving science, managing uncertainty explicitly, and supporting iterative decision-making rather than static prescriptions.

This paper examines the UF/IFAS Nutrient Management Program as a statewide governance framework supporting agro-ecological transition under these conditions. Rather than emphasizing crop-specific fertilizer response data, the paper focuses on institutional architecture, adaptive governance, and the

integration of science, policy, irrigation management, and implementation within Florida's statewide BMP program.

2. POLICY CONTEXT AND BMP FRAMEWORK

Florida's agricultural Best Management Practices program, administered by the FDACS Office of Agricultural Water Policy (OAWP), provides the statewide framework for reducing nutrient and water impacts from agriculture while maintaining economic viability. Commodity-specific BMP manuals integrate nutrient management, irrigation scheduling, water conservation practices, and water resource protection measures. Producers who enroll in the BMP program and properly implement required practices receive a presumption of compliance with state water quality standards.

Beginning in 2021, legislative directives required UF/IFAS to evaluate fertilizer application rates, expand nutrient management research across multiple cropping systems, and develop interim nutrient recommendations aligned with BMP implementation needs. Unlike traditional research programs that prioritize publication timelines, the UF/IFAS Nutrient Management Program operates under fixed legislative reporting schedules and explicit accountability requirements. In Florida's sandy soils and high-rainfall environments, irrigation management directly affects nutrient movement, nutrient use efficiency, and water quality outcomes. Excess irrigation can increase nitrate leaching below the root zone, while insufficient irrigation can reduce nutrient uptake efficiency and crop performance. Consequently, nutrient recommendations embedded within the BMP framework cannot be separated from irrigation management practices. The statewide BMP program therefore integrates nutrient application guidance with irrigation scheduling, water conservation practices, and soil moisture management to reduce nutrient losses while sustaining agricultural productivity.

3. PROGRAM ARCHITECTURE AND GOVERNANCE DESIGN

The UF/IFAS Nutrient Management Program coordinates more than fifteen concurrent research projects distributed across Florida's diverse agricultural regions (Figure 1.). These projects encompass multiple crop systems, soil types, irrigation practices, and climatic conditions. Rather than functioning as isolated investigations, projects are structured to contribute to centralized synthesis and statewide recommendation development.

This multi-scale framework links plot-scale experimentation, regional synthesis, and territorial decision-making. Individual investigators maintain autonomy over experimental design and data collection, while program leadership focuses on coordination, evidence integration, legislative reporting, and policy interfacing. This separation of roles allows scientific expertise to remain embedded within field research while enabling consistent and transparent decision-making at the statewide scale.

Decision pathways typically involve aggregation of data across projects, evaluation of evidence sufficiency, identification of uncertainty and data gaps, development of interim recommendations, and communication through Extension and BMP implementation channels. The resulting governance structure shifts nutrient management from a static recommendation model toward an adaptive, process-oriented framework (Figure 2).

4. CASE EXAMPLE: PHOSPHORUS RECOMMENDATION REVISION

Recent revisions to phosphorus recommendations illustrate the adaptive governance approach used within the UF/IFAS Nutrient Management Program. Legacy soil testing methodologies and historical phosphorus calibration systems showed inconsistencies across regions and cropping systems, creating uncertainty regarding appropriate application rates and environmental risk. UF/IFAS coordinated multiple field trials and data synthesis efforts to evaluate crop response to phosphorus under varying irrigation conditions, soil types, and production systems. The process revealed substantial spatial variability in phosphorus response and limitations in applying uniform recommendation approaches across Florida's agricultural systems. At the same time, producers and policymakers required actionable guidance to

support BMP implementation and nutrient management decisions. Waiting for complete long-term certainty would have delayed implementation and weakened the practical utility of the BMP program. As a result, interim phosphorus recommendations were developed using the best available evidence while additional data collection and recalibration efforts continued. This approach illustrates how governance structures can support adaptive decision-making under uncertainty. Recommendations were framed as provisional and revisable rather than permanent or universally optimal. Documentation of assumptions, limitations, and revision pathways-maintained transparency and scientific credibility while allowing producers to adjust nutrient management practices in a timely manner.

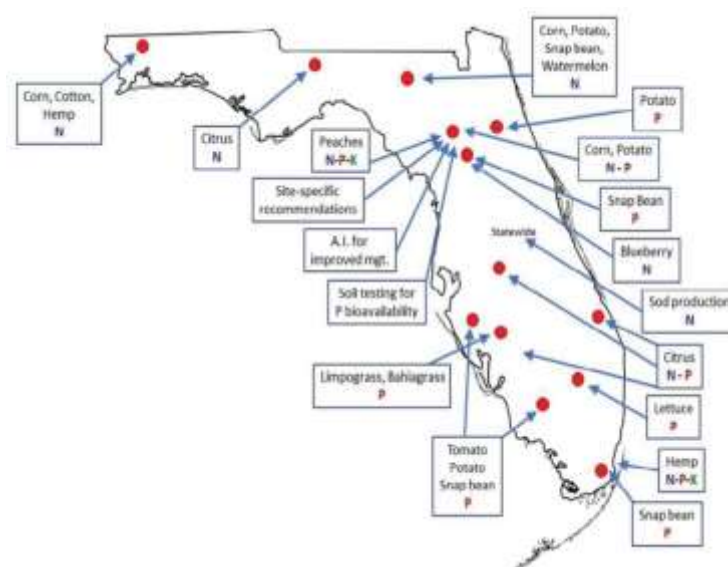


Figure 1. Location of individual Nutrient Management program research sites, crops and nutrients studied.



Figure 2. Conceptual nutrient governance pathway.

5. MANAGING SCIENTIFIC UNCERTAINTY

Under conventional agronomic research frameworks, uncertainty is typically resolved through replication and extended experimentation. Under legislative mandates, however, decisions must proceed in parallel with ongoing research. Interim recommendations therefore function not as scientific compromises, but as governance tools enabling progress toward agro-ecological transition while preserving the capacity for revision. Modeling and digital tools are incorporated as supporting infrastructure rather than primary

decision drivers. Process-based crop models, machine learning approaches, and sensor-based monitoring systems are used to evaluate scenarios, identify risk envelopes, and assess consistency with field observations. These tools extend insights across space and time but are not treated as replacements for field experimentation. Adaptive governance approaches recognize uncertainty as an inherent feature of complex socio-ecological systems. In irrigated agriculture, spatial heterogeneity, climatic variability, and management diversity limit the feasibility of universal nutrient prescriptions. Consequently, the UF/IFAS framework emphasizes iterative learning, transparent revision mechanisms, and explicit documentation of assumptions and data gaps.

6. DATA GOVERNANCE AND EVIDENCE INTEGRATION

One of the most consequential aspects of the program involves management and integration of heterogeneous datasets. Multi-institutional, multi-crop research generates data that vary substantially in format, quality, and completeness. Without standardization, synthesis becomes subjective and recommendation development becomes difficult to defend scientifically and politically.

To address this challenge, the program developed standardized data templates, reporting requirements, and quality assurance protocols. These systems enable transparent comparison across projects, identification of consistent patterns despite site-specific variability, and explicit recognition of data limitations. Effective data governance strengthens the capacity for adaptive nutrient management and supports integration of research outputs into BMP manuals and implementation guidance. The resulting infrastructure facilitates knowledge transfer, enhances transparency, and supports accountability to both policymakers and agricultural stakeholders.

7. EXTENSION, ADOPTION, AND FEEDBACK LOOPS

Extension programs play a central role in translating nutrient recommendations into practice and generating feedback for future revisions. Adoption of enhanced-efficiency fertilizers, revised nutrient rates, and site-specific management strategies provides real-world evidence that complements experimental findings. Rather than functioning solely as dissemination systems, Extension networks operate as iterative feedback mechanisms linking producers, researchers, and policymakers. Producer experiences, implementation challenges, and observed outcomes inform subsequent refinements to nutrient recommendations and BMP guidance. BMP implementation verification activities administered through the OAWP also contribute valuable information regarding adoption patterns and operational feasibility. These feedback loops reinforce the adaptive nature of the governance framework and strengthen the connection between scientific research and practical implementation.

8. OUTCOMES AND IMPLICATIONS

The UF/IFAS Nutrient Management Program has produced several outcomes relevant to agro-ecological transition and statewide BMP implementation. These include development of interim nutrient recommendations across multiple crops and regions, expansion of nutrient management research across multiple crops, refinement of phosphorus fertilizer guidance, identification of limitations in existing soil diagnostic systems, and establishment of structured pathways for iterative recommendation revision.

The Florida case demonstrates several broader implications for nutrient governance in irrigated agriculture. First, governance structures strongly influence how effectively scientific evidence can inform agricultural practice. Second, uncertainty is unavoidable in complex environmental systems and must be managed explicitly rather than ignored. Third, policy timelines and implementation needs are real constraints that shape the usability of scientific outputs. Finally, integration and coordination across institutions and knowledge systems are often more valuable than isolated technological optimization.

These lessons are relevant beyond Florida and may provide transferable insights for regions seeking to integrate nutrient and water management science into policy-driven agricultural systems.

9. DISCUSSION

Agro-ecological transition is often framed primarily as a technical challenge requiring improved technologies or agronomic practices. However, sustainability science increasingly emphasizes that transitions at scale are equally constrained by governance systems shaping how knowledge is generated, interpreted, and applied (Duru et al., 2015). The UF/IFAS Nutrient Management Program demonstrates how institutional design can become a central determinant of whether agro-ecological principles can be operationalized under real-world policy conditions. A defining feature of this case is that nutrient management decisions are required on legislative timelines rather than experimental timelines. Research on the co-production of science and policy suggests that usability, legitimacy, and timeliness are often as important as technical precision in policy-oriented sustainability systems (Lemos and Morehouse, 2005; Clark et al., 2016). In this context, interim nutrient recommendations become practical governance tools that support implementation while preserving opportunities for future refinement.

The program also illustrates the role of UF/IFAS as a boundary organization linking experimental science, Extension practice, and public decision-making (Cash et al., 2003). Coordination across projects, standardized evidence integration, and adaptive revision processes enable nutrient governance systems to function despite uncertainty and environmental variability.

Importantly, irrigation management cannot be separated from nutrient governance in Florida's irrigated production systems. Water movement directly influences nutrient transport, nutrient use efficiency, and environmental outcomes. Consequently, nutrient recommendations embedded within the BMP framework function as integrated nutrient-water management strategies rather than isolated fertilizer prescriptions. Taken together, the Florida case demonstrates that agro-ecological transition depends not only on agronomic innovation, but also on governance systems capable of aligning science, irrigation management, public policy, and practical implementation under conditions of uncertainty.

10. CONCLUSIONS

This paper examined the UF/IFAS Nutrient Management Program as a legislatively mandated governance framework supporting agro-ecological transition within Florida's statewide BMP program. The primary contribution lies not in crop-specific fertilizer response results, but in the institutional mechanisms enabling nutrient management decisions to be made under fixed timelines, public accountability, and evolving scientific evidence. The Florida experience demonstrates that effective nutrient governance requires adaptive decision-making, transparent uncertainty management, integration of irrigation and nutrient management, and iterative feedback between research, policy, and implementation. As nutrient and water management challenges intensify globally, governance frameworks capable of integrating diverse evidence streams may become as important as technological innovation itself. The governance approach described here may provide transferable insights for other regions facing nutrient impairment challenges, irrigated agricultural production, and policy-driven implementation timelines.

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