

Current Knowledge, Gaps, and Future Needs for Keeping Water and Nutrients in the Root Zone of Vegetables Grown in Florida

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SUMMARY. The success of the best management practices (BMPs) program for vegetables in Florida is measured by the level of BMP implementation and the improvement of water quality. Both require keeping water and fertilizer in the root zone of vegetables. The University of Florida Institute of Food and Agricultural Sciences (UF/IFAS) Extension Vegetable Group has identified the fundamental principles of 1) basing UF/IFAS production recommendations on the rigors of science and the reality of field production; 2) replacing the out-of-date paradigm “pollute less by reducing nutrient application rates” with “improve water management and adjust fertilizer programs accordingly”; 3) engaging growers, consultants, educators, and regulators in open-channel discussions; and 4) regularly updating current fertilization and irrigation recommendations for vegetables grown in Florida to reflect current varieties used by the industry. The group identified 1) developing ultralow-flow drip irrigation; 2) assisting conversion from seepage to drip irrigation; 3) using recycled water; 4) developing controlled-release fertilizers for vegetables; 5) developing real-time management tools for continuous monitoring of soil water and chemical parameters; 6) developing yield mapping tools for vegetable crops; 7) developing and testing drainage lysimeter designs suitable for in-field load assessment; and 8) using grafting and breeding to develop commercially acceptable varieties with improved nutrient use efficiency by improving morphological, biochemical, and chemical traits as new strategies to keep nutrients in the root zone. These strategies should become funding priorities for state agencies to help the vegetable industry successfully transition into the BMP era.

Best management practices (BMPs) are cultural practices that aim at improving the quality of Florida waters while maintaining or improving productivity [Florida Department of Agriculture and Consumer Services (FDACS), 2005]. Because water is the carrier of soluble nutrients and sediments, the overall goal of BMP implementation is to keep water and nutrients in the root zones of vegetables. This report 1) describes the typical nutrient management systems used in Florida for vegetable crop production; 2) compiles known estimates of nutrient load; 3) discusses the feasibility of zero-discharge systems for vegetables; 4) assesses the potential role of breeding and grafting on improving vegetable crop nutrient use efficiency; and 5) develops a vision on what the Florida vegetable industry at large could do to improve water

quality. The state agencies involved in BMP in Florida are FDACS, the Florida Department of Environmental Protection, the five water management districts of Florida, and the University of Florida Institute of Food and Agricultural Sciences. These agencies may find these topics useful in planning and coordinating funding allocation, identifying future research

needs, and supporting educational programs.

Current nutrient and water management practices used by Florida producers

Vegetables are grown on three main types of soils (sandy, organic, and calcareous soils) using three main types of irrigation methods (overhead, drip, and/or seepage irrigation), two main types of production systems (bare ground or mulched crop), and three seasons (fall, winter, and spring). This diversity creates a wide array of production systems over varying weather conditions, each having its own requirements for water and nutrient management. These systems were recently reviewed in a white paper published by the UF/IFAS Vegetable Fertilizer Task Force (Cantliffe et al., 2006). Production recommendations support the use of on-farm weather data, soil tests, soil moisture-sensing devices (mostly for drip- and overhead-irrigated crops), water table monitoring tools (for seepage-irrigated crops), whole-leaf analysis, and/or petiole sap tests to schedule irrigation and monitor crop nutrition. Success stories on how these tools have helped improve on-farm water and nutrient management have been reported with muskmelon (*Cucumis melo*) and watermelon (*Citrullus lanatus*) (Simonne et al., 2005) and strawberry [*Fragaria xananassa* (Hochmuth et al., 2003c)].

Crop-by-crop fertilizer recommendations for vegetables grown on sandy soils may be found in the Vegetable Production Handbook for Florida (Olson and Simonne, 2007). UF/IFAS fertilizer recommendations include a base fertilizer rate and a supplemental application allowed after a leaching rain (defined

Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
0.1242	gal/100 ft	L·m ⁻¹	8.0520
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	kg·ha ⁻¹	0.8922
16.0185	lb/ft ³	kg·m ⁻³	0.0624
28.3495	oz	g	0.0353
305.1517	oz/ft ²	g·m ⁻²	0.0033
1	ppm	mg·kg ⁻¹	1
1	ppm	mg·L ⁻¹	1

as 3 inches of rainfall in 3 d or 4 inches in 7 d), an extended harvest season, and/or when plant nutritional status is diagnosed as “low” based on whole leaf analysis or petiole sap testing. Recommendations also include fertilizer placement (banded, broadcast, or modified broadcast), fertilizer sources when necessary, preplant fertilizer application amounts, and fertilization schedules. These fertilizer recommendations, based on research from the 1980s and 1990s, propose a single nitrogen (N) rate for all irrigation systems, production seasons, and Florida soil types (Olson and Simonne, 2007). Recommendations for phosphorus (P), potassium, calcium, magnesium, and micronutrient applications on sandy soils are based on Mehlich 1 soil test results. Recommendations for vegetable crops grown on muck soils are available (Hochmuth et al., 2003a, 2003b). Fertilizer recommendations for vegetable crops grown on the calcareous soils of southern Miami-Dade County are currently incomplete because no calibrated soil test is available for the area (Li et al., 2006a, 2006b, 2006c, 2006d, 2006e, 2006f, 2006g, 2006h, 2006i, 2006j). In the absence of a calibrated soil test for this Florida soil type (ammonium bicarbonate–diethylene triamine

penta-acetic acid extractant has been considered), fertilizer recommendations and, hence, practices are based on experience and results of whole leaf analysis and/or petiole sap testing.

UF/IFAS irrigation scheduling recommendations for vegetable crops grown with seepage irrigation are to maintain the water table at the 15- to 31-cm depth when plants are small and at the 31- to 61-cm depth when plants are fully grown. Irrigation recommendations for vegetables grown with overhead and drip irrigation include to 1) use an evapotranspiration (ET) -based target volume; 2) fine-tune volume based on soil moisture level; 3) split irrigation to limit water movement below the root zone; and 4) keep records of irrigation practices (Simonne et al., 2007). As recommended by the UF/IFAS Vegetable Fertilizer Task Force, research results on fertilizer and irrigation management developed in the context of the BMP and published in refereed journal articles since the early 2000s need to be incorporated into UF/IFAS recommendations (Cantliffe et al., 2006). Recently approved updates to UF/IFAS fertilization recommendations from the UF/IFAS Vegetable Fertilizer Task Force were to 1) adopt preliminary N recommendations for drip-irrigated grape tomato (*Solanum lycopersicum* var. *cerasiforme*); 2) report lack of efficacy of foliar-applied calcium sprays to improve strawberry yields and postharvest quality; and 3) increase by 25% N fertilization recommendation for seepage-irrigated crops to compensate for denitrification losses (UF/IFAS Plant Nutrient Oversight Committee, unpublished data).

Current methods for load measurement and available estimates

Quantifying nutrient load from vegetable production systems is the first step toward monitoring groundwater pollution in the field and understanding how each group of BMP contributes to load reduction. A nutrient load is defined as the weight of a chemical entering or leaving an area, and it is calculated as the product of the volume of water that the chemical is transported in and the concentration of the chemical in the water (Rice and Izuno, 2001). Past research has focused mostly on improving

estimation of nutrient concentration, and several assumptions are often made in determining the corresponding volume of water on a per-acre basis. This is important for vegetable crops grown on raised beds because the leaching or wetted surface depends on bed compaction, width, and spacing (Farneselli et al., 2008). Load estimates may vary from simple to double based on the assumptions made on the size and shape of the wetted zone (Farneselli et al., 2008). Because nutrient concentration and size/shape of the wetted zone are equally important for in-field load determinations, they should be estimated with the same level of accuracy.

Nutrient load can be determined indirectly or directly. The indirect approaches of measuring load include nutrient flow models and nutrient balances. Nutrient flow models are important tools for evaluating the impact of nutrient leaching on water quality at the watershed level and play an important role in designing agricultural and environmental policies. Direct methods for calculating load at the field level are resin traps, soil sampling, or drainage lysimeters (Farneselli et al., 2008; Pampolino et al., 2000; Zotarelli et al., 2007). Although each of these methods has its own advantages and limits, small, in-row drainage lysimeters are emerging as a practical tool for direct load measurements (Gazula et al., 2006; Migliaccio et al., 2006; Zotarelli et al., 2008). A partial vacuum may be added to low-cost drainage lysimeters to prevent water logging without compromising the accuracy of the results (Evelt et al., 2006). At 0.0013 mm, accuracy of drainage measurement was nearly two orders of magnitude better than that of the lysimeter weight measurement (1 mm), ensuring that the continuous drainage measurement may be included in the weight balances determination of ET without diminishing the accuracy of ET values (Evelt et al., 2006).

Few in-field load estimates have been published for vegetables, and few of those were developed on sandy soils applicable to Florida (Table 1). Load estimates ranged from 1 to 400 kg-ha⁻¹ of N and varied based on crops, cultural practices, and irrigation/fertilizer management, but also based on the methodology used for extrapolating load calculations to

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Table 1. Published estimates of nitrogen (N) load for selected crops.

Crop	Soil type	Location	Method ^z	Original N load estimate ^y	Original unit	Standardized N load estimate ^x (kg·ha ⁻¹)	Reference
Artichoke	Loam ^w	Spain	SS	287–406 NO ₃ -N	kg·ha ⁻¹	287–406	Ramos et al., 2002
Carrot	Loamy sand	California	RT	0.97 NO ₃ -N 0.26 NH ₄ -N	mg·kg ⁻¹ of soil	1.85	Allaire-Leung et al., 2001
Cauliflower	Loam ^w	Spain	SS	168–272 NO ₃ -N	kg·ha ⁻¹	168–272	Ramos et al., 2002
Corn	Silt loam	Argentina	SCL ^v	0–94 NO ₃ -N	kg·ha ⁻¹	0–94	Aparicio et al., 2008
	Silt loam-loam	California	SS	14–62 mineral-N	mg·kg ⁻¹ of soil	21–93	Paudel et al., 2004
	Fine loamy	Nigeria	SS	13–114 mineral-N	kg·ha ⁻¹	13–114	Oikeh et al., 2003
	Silty clay loam	Spain	SS	1–14 NO ₃ -N	mg·kg ⁻¹ of soil	1.5–21	Daudén and Quilez, 2004
	Sandy	Washington	M	3–28 NO ₃ -N	kg·ha ⁻¹	3–28	Peralta and Stockle, 2002
Onion	Clay loam	Colorado	SS	25–286 NO ₃ -N	kg·ha ⁻¹	25–286	Halvorson et al., 2002
	Sandy loam	India	SS	25–95 NO ₃ -N	mg·kg ⁻¹ of soil	38–142	Rajput and Patel, 2006
	Loam ^w	Spain	SS	198–474 NO ₃ -N	kg·ha ⁻¹	198–474	Ramos et al., 2002
Orange	Fine sand	Florida	DL	174–252 mineral-N	g/lysimeter ^u	NE ^t	Syvertsen and Jifon, 2001
Potato	Loamy sand	Minnesota	SS	20–58 mineral-N	kg·ha ⁻¹	20–58	Zvomuya et al., 2003
	Loamy sand	Canada	SCL	4–228 NO ₃ -N	kg·ha ⁻¹	4–228	Macaigne et al., 2008
	Loam ^w	Spain	SS	8–120 NO ₃ -N	mg·kg ⁻¹	12–180	Ramos et al., 2002
	Sandy	Washington	M	60–308 NO ₃ -N	kg·ha ⁻¹	60–308	Peralta and Stockle, 2002
Tomato, processing	Silt loam-loam	California	SS	3–69 NO ₃ -N	kg·ha ⁻¹	3–69	Paudel et al., 2004
Tomato, fresh-market	Calcareous	Spain	SCL	26–42 mineral-N	mg·kg ⁻¹ of soil	39–63	Vázquez et al., 2006
	Sandy loam	France	SS	155–421 NO ₃ -N	kg·ha ⁻¹	155–421	Lecompte et al., 2008
	Sandy loam	Georgia	SS	50–800	mg·L ⁻¹	NE	Yaffa et al., 2000
	Sandy loam	Georgia	SS	10–110 mineral-N	mg·kg ⁻¹ of soil	15–165	Sainju et al., 1999
	Sand	Florida	DL	7–250 NO ₃ -N	kg·ha ⁻¹	7–250	Zotarelli et al., 2007
			DL	5–30 NO ₃ -N	kg·ha ⁻¹	5–30	
			SCL	5–37 NO ₃ -N	kg·ha ⁻¹	5–37	
			DL	3–4 NO ₃ -N	kg·ha ⁻¹	3–4	
Bell pepper	Gleysol hydroameliorated	Croatia	DL	1–16 NO ₃ -N	kg·ha ⁻¹	1–16	Romic et al., 2003
	Sand	Florida	SS	9–38 NO ₃ -N	kg·ha ⁻¹	9–38	Zotarelli et al., 2007
			DL	6–37 NO ₃ -N	kg·ha ⁻¹	6–37	
			SCL	2–21 NO ₃ -N	kg·ha ⁻¹	2–21	
Hot pepper	Sandy loam	China	SCL	17–54 NO ₃ -N	g·m ⁻²	NE	Zhu et al., 2005
Wheat	Loam	Spain	SS	54–1211 NO ₃ -N	kg·ha ⁻¹	54–1211	Abad et al., 2004
Zucchini	Sand	Florida	SS	21–34 NO ₃ -N	kg·ha ⁻¹	21–34	Zotarelli et al., 2007
			DL	20–26 NO ₃ -N	kg·ha ⁻¹	20–26	
			SCL	11–15 NO ₃ -N	kg·ha ⁻¹	11–15	
	Sand	Florida	SCL ^s	2–45 NO ₃ -N	kg·ha ⁻¹	2–45	Zotarelli et al., 2008

^zSS = soil sampling; RT = resin trap; SCL = suction cup lysimeter; M = modeling with CropSyst (Stockle et al., 1994); DL = drainage lysimeters.^yNO₃-N = nitrate N; NH₄-N = ammonium N; mineral N = NO₃-N + NH₄-N; 1 kg·ha⁻¹ = 0.8922 lb/acre; 1 mg·kg⁻¹ = 1 ppm; 1 g·m⁻² = 0.0033 oz/ft²; 1 mg·L⁻¹ = 1 ppm.^xN load estimates calculated based on 2-ft (0.61 m) bed width and 1450 kg·m⁻³ (90.52 lb/ft³) soil bulk density.^wLoam, sandy loam, or clayey loam.^vDrainage was estimated with LEACH_W model that uses the equation $b=a\left(\frac{\theta}{\theta_s}\right)^{-b}$, in which θ is the volumetric water content, θ_s is the volumetric water content at saturation, and a and b are constants (Aparicio et al., 2008).^tNE = not estimable based on information in original report.^uWater collected by suction and drainage into container.

a per-hectare basis. Hence, efforts should be made to standardize protocols and methodology for in-field load estimation. In addition, the link between irrigation management and nutrient leaching shows that education on irrigation and nutrient management is central to BMP implementation. In-field load assessment should be considered a funding priority by state agencies. An increased fertilizer rate does not directly translate into an increase in load. This first requires the development of reliable methods and tools of known precision because watershed-level load simulations are poor indicators of actual field-level leaching. The effect of all fertilizer recommendations on nutrient load should be determined for all major vegetable crops through on-farm research projects in regionally appropriate production areas.

Zero-discharge systems

Achieving zero-discharge systems would ensure that water is kept in the root zone of vegetables. In theory, spodosols allow for a natural zero-discharge system when the spodic layer is continuous and in the absence of rain. In short, spodosols have an impermeable layer that transforms a field into a giant bathtub. When it rains, water needs to be pumped out of the field to prevent flooding. Currently, a zero-discharge system on deep sand soils does not seem technically feasible in field production (past attempts to create physical barriers of concrete or plastic have failed). By contrast, it can be done relatively simply in greenhouse production. Attempts to modify soil water-holding capacity in open fields by using organic (compost, modified corn starch, polyacrylamides) or inorganic (zeolites) amendments are economically and technically not feasible as a result of the large quantities of material needed (Bhardwaj et al., 2007; Sepaskhah and Yousefi, 2007; Sivapalan, 2006; Vachere et al., 2003).

Cover crops are often presented as an underused BMP. Cover crops may be used to compete with weeds (Linares et al., 2008), return biomass and nutrients to the soil (Muñoz-Arboleda et al., 2008; Schomberg et al., 2007), and retain pesticide residues (Potter et al., 2007). However, cover crops are not used as often as expected because more research is

needed to 1) identify suitable cover crops for different seasons in Florida; 2) assess the role of a cover crop in the life cycle of crop pests (disease, insect, and virus); and 3) quantify the real capability of nutrient scavenging of each cover crop. Cost and seed availability are also cited as impediments to a broader use of cover crops. Hence, as a result of the low water-holding capacity of Florida sandy soils and unpredictable rainfall patterns, zero discharge in field production should be considered a reachable goal, but in the long term, “quasi-zero discharge” may be more realistic.

Catch ponds are sometimes used to collect excess rainfall in seepage-irrigated systems. However, ponds represent a large capital investment and permanently occupy land. The use of polyacrylamide blocks or zeolite filters located at key structures/discharge points have shown promise to trap soluble nutrients and sediments in arid environments (Zreig et al., 2007). Limited research has been conducted so far by UF/IFAS on this topic, but engineering firms have successfully used this technology on construction sites throughout Florida. However, peak volumes during storm events may be excessively large on commercial operations, thereby limiting this practice. Zero-discharge systems in mulched and drip-irrigated fields with deep sandy soils may be approachable if drip irrigation application rates can match hourly crop ET rates. This will require slight modification of existing systems (filters and pipes) and the development of ultralow-flow drippers.

Controlled-release fertilizers [CRFs (mostly for N)] should also be part of the zero-discharge approach. Currently, limited information is available on the use of CRFs for vegetables, except potato [*Solanum tuberosum* (Hutchinson, 2004; Pack et al., 2006; Simonne and Hutchinson, 2005)]. An ongoing project is assessing seepage-irrigated tomato and bell pepper (*Capiscum annuum*) responses to CRFs in southern Florida. Research on developing CRF-based fertilization programs should be supported for all the main crops grown with seepage irrigation, including potato, tomato, bell pepper, eggplant

(*Solanum melongena*), watermelon, and cabbage (*Brassica oleracea* var. capitata).

Potential role of breeding and grafting on improving vegetable crop nutrient use efficiency

Together with adjustment in cultural practices, load reduction may be accomplished by using varieties selected for improved nutrient uptake characteristics. Most public breeding programs focus on developing parents for hybrids, whereas private breeding programs mostly produce industry-ready varieties. With the exception of N-efficient potato varieties from Europe, improved nutrient use efficiency (NUE) is rarely the main focus of either type of vegetable breeding programs. Overall, breeding for improved pest resistance is the main focus. By using high fertility rates in breeding programs, little emphasis is placed on “passively” selecting for high NUE varieties. Hence, public and private breeding programs will have to be committed to NUE in the parents and new commercial varieties released.

Efforts to improve NUE have been conducted in the last 40 years on food crops of worldwide importance such as wheat [*Triticum aestivum* (Abad et al., 2004; Chao et al., 2007)], corn [*Zea mays* (Halvorson et al., 2002)], and bean [*Phaseolus vulgaris* (Beebe et al., 2006)] with emphasis on horticultural productivity and nutritional quality of the harvested plant part. Differences in nutrient uptake patterns among genotypes within a genus are known for many vegetable crops, including tomato (JianJun and Gabelman, 1995; O’Sullivan et al., 1974), cabbage (JinKiu et al., 2006; Tanaka and Sato, 1997), potato (Shahnazari et al., 2008; Sharifi and Zebarth, 2006; Sharifi et al., 2007), and pumpkin [*Cucurbita pepo* (Swiader et al., 1994)]. However, the focus of these research projects was mostly to document phenotypical differences or to improve the adaptation of current lines to areas of poor growing conditions (such as salinity or micronutrient deficiencies) rather than identify genes involved in nutrient uptake. Breeding approaches that may increase plant nutrient use efficiency

include 1) anatomical modifications of root system architecture, including increased branching and number of small, absorbing roots (Beebe et al., 2006; Frith and Nichols, 1975; Muñoz-Arboleda et al., 2006; XiangRong et al., 2005); 2) chemical

modification of the soil around the roots that increase the availability of nutrients [release of phosphatases that make P more available (George et al., 2005) or citrate that lower and buffer the pH near the roots (Schenk, 2006)]; 3) biochemical

modification of the root surface by increasing the number of absorption sites on each root (Cuartero and Fernandez-Muñoz, 1999); and 4) understanding the regulation of genes involved in nutrient uptake (Chao et al., 2007).

Table 2. Summary of current best management practice (BMP) research areas for vegetables grown in Florida, level of knowledge, and gaps.

BMP research area	Level of knowledge	Gaps
Fertilizer recommendations	Foundation work complete for major crops	Need regular updates Need provisions for El Niño southern oscillation (ENSO) phases and expected frequency of leaching rainfall Need to abandon single-number recommended rates Education need to focus on reducing preplant rates with drip
	Limited or incomplete for herbs No fertilization recommendations for organic vegetable production	All work on organics needs to be done Need for funding to conduct research
Irrigation recommendations	Seasonal water use estimates complete for major crops	Need automated, sensor based irrigation systems Need to match irrigation zones to soil type Need to rename “reclaimed water” with “recycled water” Need to generalize the use of recycled water as irrigation water: nutrient contribution and food safety aspects need to be clarified Demonstrations needed to show reduced irrigation when plants are small
Fertilizer recommendations for the use of controlled-release fertilizer	Advanced for seepage-irrigated potato; work underway on tomato and bell pepper	Work needed for all seepage irrigated crops grown on the organic and sandy soils of Florida
Direct nutrient load measurements	Lack of widely accepted methodology and effect of soil types makes comparisons of load estimates difficult among studies; assumptions made on published load calculations are sometimes unrealistic or not met	Impact on water quality needs to be determined Need a simple, reliable drainage lysimeter for on-farm monitoring Need to use lysimeter for direct assessment of BMP effect on water moving below the root zone and load
Zero-discharge systems	Virtually none in field production; good concept, but may be unrealistic in practice	Need to pursue ultralow-flow drip Need to pursue use of polyacrylamide and zeolite filters
Breeding and genetics	Virtually none in the context of BMP	Need breeder’s and administration’s commitment Need to investigate morphological, biochemical, and chemical strategies Need to use grafting
Nutrient sensors	Virtually all soil chemical information is based on soil sampling	Need specific nitrate, ammonium, phosphorus, and electrical conductivity sensors that are inexpensive and reliable Data should be displayed through a user-friendly interface
Cover crops	Lots of information about effect on soil physical and chemical properties; limited information on actual load reductions caused by nutrient trapping	Need reliable seed source and on-farm demonstration Need to assess long-term effect of cover crop use on nutrient load

Table 3. Questions to and summary of vision statements by key University of Florida Institute of Food and Agricultural Science (UF/IFAS) state and county faculty with active programs in best management practices (BMP) for vegetable crops.

Question	Answers	Comments
1. What is your opinion/vision for the next 5 years on what the vegetable industry needs to do to improve their irrigation management?	Use recycled water Improve irrigation scheduling at the beginning and throughout the season Routinely use soil moisture measuring devices (drip) or water table indicators (seep) Consider and initiate a switch from seepage to drip irrigation Consider buried drip Increase the precision of overhead (pivot) irrigation Become more familiar with the capacity and function of existing drip systems	Note “recycled” rather than “reclaimed” Applies to drip and seepage irrigation Emphasis should be placed on reliability, cost, and simplicity of data collection/retrieval Mixed systems (seepage + drip) may be a transition step
2. What is your opinion/vision for the next 5 years on what the industry need to do to improve their fertilizer management?	Recalculate break even cost for fertilizers Improve irrigation scheduling methods Use tissue, sap test, SPAD readings, or other spectral method as a monitoring tool Integrate leguminous cover crops in production system and/or nitrogen trap crops after the production season Apply less fertilizer more often (drip) Use nutrient-efficient varieties Move to season irrigation system soil type-specific nutrient recommendations [especially for nitrogen (N)] Increase industry confidence in UF/IFAS recommendations through regular updates and on-farm demonstrations For crops like strawberry, N recommendations should be based on vegetative growth	This was recommended by the UF/IFAS Vegetable Fertilizer Task Force This was recommended by the UF/IFAS Vegetable Fertilizer Task Force
3. What educational programs are needed? (need to be separated for agents and for growers)	Hands-on workshops on nutrient/irrigation management for small farmers and middle management/foreman level for large growers Continue the face-to-face work of the BMP implementation teams Support the one-on-one work of the mobile irrigation laboratory (MIL) to all vegetable farms that use drip and seepage irrigation Support educational role of the BMP Implementation Teams Cover crop management Myth-breakers on some inaccurate “common wisdoms” on fertilizer management Spray equipment and fertilizer injection calibration	Similar workshops have been locally offered in Homestead, Immokalee, the Tri-County Agricultural Area, and North Florida Research and Education Center-Suwannee Valley; “basic” and “advanced” levels are needed Fertilizer management advice relevant in other parts of the country may not apply to Florida

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Table 3. (Continued) Questions to and summary of vision statements by key University of Florida Institute of Food and Agricultural Science (UF/IFAS) state and county faculty with active programs in best management practices (BMP) for vegetable crops.

Question	Answers	Comments
4. What are the critical issues on the horizon (5 to 10 years) that may affect the industry?	Food safety-related liability Increasing cost of energy and reduced profit margins Increased cost of fertilizers Increased cost of food safety compliance Loss of methyl bromide Reduction in water permitted may require switching to drip, use ultralow-flow, and recycled water “Distractions” caused by food safety, labor, land availability, and reduced state funding may push water quality efforts and compliance to “the back burner” Maintain UF/IFAS relevance to the industry	
5. Additional comments	Restrict the use of Mehlich 1 soil test to soils with pH <7.2 and use another soil test when pH >7.2 Consider greenhouse or high tunnel as an alternative to field production	

Table 4. Strategic areas of future research for improving the quality of Florida waters, their respective approaches, and estimated chances of success.

Approach used to improve water quality	Possible areas of research	Estimated relative chance of success	Why?
Increase soil water-holding capacity	Organic soil amendments	Low	Cost
Increase soil water-holding capacity	Inorganic soil amendments	Low	Cost
Filter water at key points	Polyacrylamide blocks	High, short term	Technology already in use for water treatment for phosphorus and ammonium
Improve plant nutrient uptake efficiency: better root systems	Breeding and genetics	High, long term	Lack of emphasis from breeders, cost; indirect link with water quality improvement
Improve plant nutrient uptake efficiency: synchronizing the expression of genetic progress in root and shoot	Grafting	High, short and long term	Grafting is a tool, not an end for pest management; could be used with breeding efforts with high nitrogen use-efficiency rootstocks

With all the plant physiology knowledge developed since the 1970s and the recent progress in genomics, breeding for root systems with improved NUE may soon become a reality. It will require the commitment of UF/IFAS breeding programs and the identification of all the genes that code for the phenotype of interest. Projects should link together soil chemistry, plant biochemistry, plant physiology, and genomics. Although this type of effort may

contribute to BMP adoption and improvement of water quality, the full funding of these long-term, basic projects may be beyond the scope of funding by the Florida agencies involved in the BMP program. However, these agencies could partially support these projects.

Traditionally, breeding has focused on improving the genotype of a single (open-pollinated) or two (hybrid) parents. Vegetable grafting is an innovative technique successfully

practiced in Asia, parts of Europe, and the Middle East that develops a new plant by physically uniting two plants (the rootstock and the scion) through the graft (Edelstein, 2004; Lee, 2007). Resistant rootstocks, grafting methods, and procedures are being developed primarily on tomato, eggplant, and watermelon for the management of soilborne pathogens such as fusarium, verticillium, and nematodes. In addition to disease control, grafted plants have shown tolerance

to environmental stresses such as low temperature and salinity (Estañ et al., 2005; Lee, 1994). Because grafted vegetables often exhibit significant yield increases as a result of vigorous growth even in the absence of disease pressure, it is possible that grafting may enhance water and nutrient uptake by plants (Khah et al., 2006; Lee, 1994; Qaryouti et al., 2007). Hence, grafting may help speed the development of nutrient- and water-efficient plants. If the commercial plant material targeted is a grafted transplant, a novel approach to plant breeding could be to separately develop hybrid rootstocks and hybrid scions. Economical analysis will have to establish the breakeven point between the environmental benefit and the cost of labor and seed associated with grafting before this technique is adopted by the industry.

Vision for the next 5 years: What does the industry need to do better?

The main technically feasible practices that could be implemented or developed in the short term include 1) switching from seepage to drip irrigation; 2) identifying adequate release pattern from CRFs for seepage-irrigated crops; and 3) developing ultralow-flow drip tapes for drip irrigation (Tables 2, 3, and 4). In theory, keeping the water in the root zone of vegetable crops could be achieved by having an adjustable flow-rate emitter (by changing operating pressure) in which flow rate could match hourly crop ET. The feasibility of achieving ultralow-flow rates (1.02 to $1.53 \text{ L} \cdot \text{m}^{-1} \cdot \text{h}^{-1}$) by operating current emitters at lower pressures or developing new emitters needs to be investigated. This may require the development of partnerships with irrigation supply manufacturers. Also, the effects of low pressure on uniformity and filtration requirements need to be addressed to reduce clogging risk. We believe that ultralow-flow drip irrigation is the strategy that has the greatest potential to simultaneously keep the water in the root zone of vegetable crops and reduce water use (another challenge in Florida, but not directly tied with the BMP program). The economical feasibility of implementation of each of these practices also needs to be determined. In addition,

4) real-time, continuous sensing of soil moisture status, soil EC, and nutrient concentrations; and 5) yield mapping as a basis for nutrient application and using recycled water need to be considered. In doing so, fertilizer and irrigation management needs to be considered within a production system (and not as independent variables that can be changed as needed) and the cost of each new technique needs to be related with the value of the information provided to the grower. The development of new soil nutrient sensors and yield mapping techniques offers the attractive prospective of reducing the need for soil sampling and of linking field heterogeneity to nutrient management. Real-time field data could be used as "BMP intelligence."

Industry progress in irrigation and nutrient management in the near future is likely to depend on the general economic context (production costs, food safety issues, labor availability) and on educational programs (Simonne and Ozores-Hampton, 2006). The BMP process so far has focused on the land owner and/or on the grower. However, the commitment of the consulting and fertilizer industry to the BMP program and water quality also needs to be strengthened. Similar to what was developed for pesticides in the 1970s, a fertilizer applicator's license program coordinated by FDACS and educationally supported by UF/IFAS should be developed based on the existing Certified Crop Advisor program. In a state like Florida where UF/IFAS is not the sole direct source of information for the growers, it is essential that all segments of the vegetable industry be involved in the BMP program.

The mobile irrigation laboratories, the BMP implementation teams, and local extension offices should be supported and given the resources necessary to fully use their knowledge, experience, credibility, and connection with the growers to ensure a rapid adoption of BMP by the vegetable industry in Florida.

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