A Water and Nutrient Management Planning Process for Container Nursery and Greenhouse Production Systems in Maryland[1]

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Abstract

Many states throughout the United States are now concerned about the impact of non-point source pollution on the declining quality of water in their watersheds. In 1998, the state of Maryland adopted one of the toughest nutrient management planning laws in the nation, requiring virtually all agricultural operations to write and implement nitrogen (N) and phosphorus (P) based management plans by December 31, 2002. The nursery and greenhouse industries are faced with a complicated task to write these nutrient management plans, since these operations grow a large number of plant species utilizing a range of fertilization and irrigation strategies. A nutrient management planning strategy has been identified that will provide an assessment of nutrient loss potential from a wide variety of production scenarios, identify the specific factors that contribute most to nutrient leaching and runoff, and enable targeted best management practices to be implemented to reduce the risk of nutrient run-off.

Index words: nitrogen, phosphorus, ornamental plants, risk assessment, best management practices, BMP, non-point, water quality.

Significance to the Nursery Industry

In 1998, Maryland adopted one of the most stringent nutrient management planning laws in the nation, requiring virtually all agricultural operations to write and implement nitrogen- (N) and phosphorus- (P) based management plans by December 31, 2002. The nursery and greenhouse industries are faced with a complicated task to write these nutrient management plans, since many operations grow a large number of plant species utilizing various fertilization and irrigation strategies. In addition, crop cycles range from a few weeks in greenhouse production, to many years for some perennial species in field production. For many ornamental species, there is also an inadequate knowledge of exact nutrient requirements that will maintain optimal growth rates. These factors must be considered in the planning process, combined with any unique infrastructure and site characteristics that may contribute to water and nutrient runoff from each growing operation.

Our challenge was to identify a simple, effective process for nutrient management planning that would provide an accurate assessment of nutrient loss potential from this wide variety of production scenarios. This process needs to identify the site-specific factors that contribute most to nutrient leaching and runoff, provide a mechanism to assess the risk of nutrient runoff, and formulate specific best management practices. In this way the grower and/or nutrient management planner can choose from various cost-effective alternatives to reduce the potential for nutrient runoff, without compromising production efficiency or plant quality.

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Introduction

Many states throughout the United States (US) are concerned about the impact of non-point source pollution on the declining quality of water in their watersheds. The US Environmental Protection Agency (EPA) may soon be enforcing provisions of the 1972 Federal Clean Water Act to ensure that all states implement a Total Maximum Daily Load (TMDL) program for all watersheds (5). In turn, many state governments may promulgate laws to ensure that non-point sources of pollutants are assessed and regulated. One such law, the Maryland Water Quality Improvement Act of 1998 (7) mandates the writing and implementation of nitrogen (N) and phosphorus (P) management plans for all sectors of agriculture by December 31, 2002 (8). Prior to this act, Maryland had a voluntary nutrient management process in place that was focused on developing N-based plans for agronomic crop species (10). This process recommended best management practices for farming operations producing animal manure to reduce nutrient movement into the Chesapeake Bay. With the 1998 law, both organic and inorganic N and P applications will be regulated in varying ways for all sectors of agriculture and commercial urban nutrient applications in Maryland (9).

The agronomic nutrient management process normally takes a nutrient balance approach (5) to developing nutrient management plans, and:

- determines the presence and availability of nutrients in the soil;
- determines the nutrient removal over the season by the crop based on knowledge of the cultivar, growth rate of the crop, and the nutrient concentrations in the biomass removed, or that which remains on the land;
- adds an 'efficiency factor', which is based on nutrient removal by other mechanisms (e.g., microbial use, soil fixation, etc.); and,
- determines fertilizer application rates for each crop/soil type (or other management unit) based on the factors outlined above.

This process can be made more rigorous by utilizing a P-site index when soil phosphorus contents are high and there is a potential for soil movement from the site (1).

However, for nursery and greenhouse operations, the nutrient management planning process becomes more complicated for a number of reasons:

- nutrient use of many species, especially for herbaceous and woody perennial species, has not been adequately researched;
- growth rate and hence the nutrient uptake of many species varies with temperature, among other environmental growth factors. Many greenhouse data are valid, but outdoor nursery production data from other states are not precise;
- production times for annual species can range from weeks to months; for perennial species, production times are typically from one year to many years for large specimen trees;
- plant species are grown in a number of ways, i.e., in soil under field production, in soilless substrates in varying plastic container sizes, using different methods of irrigation;
- nutritional requirements of this wide range of species means that producers rely on a variety of fertilization methods, including conventional, slow-release and soluble fertilizers, where appropriate; and,
- container-production and greenhouse sites can be compacted, which usually means surface-water control measures are necessary to regulate runoff.

Nutrient applications are therefore just part of the story for the container nursery and greenhouse industries. Water is an integral component of the nutrient management equation, particularly where irrigation or rainfall has the ability to move soluble nutrients with ease.

Therefore, the challenge was to identify a simple, cost-effective process that:

- provides an accurate assessment of nutrient loss potential from this wide variety of production scenarios;
- identifies those *specific* (i.e., infrastructure *or* management) factors that contribute most to nutrient leaching and runoff; and,
- provides a mechanism to assess the efficiency of the various production scenarios.

The water and nutrient management process that is presented in this paper describes a 'systems-based' approach. This allows the nutrient management planner to look not only at nutrient movement from a physical point of view, but enables them to incorporate management factors that may influence nutrient leaching and runoff from plant container-production sites. The objectives of this paper are therefore to:

- introduce the concept of water and nutrient management planning, and indicate how site, substrate, irrigation and fertilization factors are incorporated into a risk assessment and risk (best) management process; and,
- outline a risk assessment approach that can be used to write nutrient management plans for any 'out-of ground' (container nursery or greenhouse) operation, regardless of differences in cultural methods.

The Maryland Nutrient Management Planning Process

This process outlines the components of the out-of-ground nutrient management planning process in Maryland, which includes any operation that grows plants in containers and soilless substrates. In keeping with the systems-based approach outlined above, site factors, nutrient application, substrate and water management practices will be discussed in sequence.

Operation Identification and Reporting Requirements. The first part of the nutrient management plan is relatively unique to the Maryland regulations (8). A cover page for the plan details the following:

- The name of the operator (the person who manages the land), the name of the operation, and contact information.
- The tax identification numbers of all leased and owned parcels of land, watershed code information (both tracking mechanisms), and the county (or counties) where the land is situated.
- Consultant information (if the plan is prepared by a consultant) and their Maryland certification and license numbers.
- The page must be signed and dated by the operator.
- The plan must be filed with the Maryland Department of Agriculture and updated every three years and/or when there is more than a 20% (or greater than 5 acre, whichever is less) change in area managed.

Description and Map/Sketch of the Operation. This part of the plan provides a description of the physical operation. One or more maps (e.g., soil survey maps or aerial photographs) must be included that clearly identify the location and boundaries of the agricultural operation, show individual growing areas and size of each area, and give the area or management unit number or identifier. A map or separate sketch of the operation should include dimensions of all houses or growing areas, roadways, irrigation lines, ditches or drainage lines, location of wells, ponds and riparian buffer areas, and any other detail that will make the plan as self-explanatory as possible.

Management Units. The first, and possibly most important part of the planning process is the development of a set of 'management units' by the planner in consultation with the grower. These management units group the nursery plant production into the *least possible* number of units, in order to simplify the planning process. Traditional agronomic nutrient management plans identify management units as 'an area sharing common characteristics, including soil type, nutrient content and the plant type or crop produced, such that nutrients can be recommended and managed in a uniform and consistent manner throughout the area' (8). However, for the reasons outlined above, management units for nursery and greenhouse crops need to be based on other criteria.

Since so many plant species are grown by most operations, plant species are purposely *not* considered as management units, unless a single species (or group of cultivars, e.g., poinsettias, azaleas, etc.) constitutes a considerable proportion of the total production. Instead, management units that simplify the planning process, yet integrate water and

Table 1. Recommended management unit categories for the container nutrient management planning process in Maryland.

Plant category	Code	Container volume	(Approximate container size)
Annual species	A1	i. Less than 1,250 cm^3	(< ½ gallon)
	A2	ii. From 1,250–2,500 cm^3	(½–1 gallon)
	A3	iii. Greater than 2,500 cm^3	(> 1 gallon)
Indoor and foliage species	F1	i. Less than 2,500 cm^3	(< 1 gallon)
	F2	ii. From 2,500–12,250 cm^3	(1–3 gallon)
	F3	iii. Greater than 12,250 cm^3	(> 3 gallon)
Herbaceous perennial species	HP1	i. Less than 2,500 cm^3	(< 1 gallon)
	HP2	ii. From 2,500–12,250 cm^3	(1–3 gallon)
	HP3	iii. Greater than 12,250 cm^3	(> 3 gallon)
Woody perennial species	WP1	i. Less than 2,500 cm^3	(< 1 gallon)
	WP2	ii. From 2,500–12,250 cm^3	(1–3 gallon)
	WP3	iii. From 12,250–26,500 cm^3	(3–7 gallon)
	WP4	iv. Greater than 26,500 cm^3	(> 7 gallon)

nutrient flow that is measured by a few 'key' variables, are recommended. The recommended management units (Table 1) initially categorize plant production by broad plant type (i.e., annuals, indoor and foliage species, and herbaceous or woody perennial species). Within each of these categories, the management units are then grouped into three or four container size categories. This approach was developed for a number of reasons:

- the plant categories often share the same type of environmental and cultural conditions;
- the plant categories often have similar growth rates, spacing requirements and production times; and,
- most growers group their plants in production areas by container size.

Since plants are often grouped by container size and spaced accordingly, these factors have an important effect on the irrigation efficiency and leaching fraction for each management unit. Container size integrates irrigation interception efficiency (plant density), leaching fraction (irrigation duration), container height (gravitational potential), and substrate physical properties into a potential runoff equation.

These factors are key variables in the risk assessment process. It is important to note that the total production should be defined in the *least possible number of units*, as this greatly simplifies the risk assessment and risk management process. We recognize that the container sizes for most greenhouse operations fall within the two smallest container sizes (Table 1), but this is taken into consideration later in the process when nutrient application, leaching fraction, and interception efficiencies are calculated.

When writing plans, it is recommended that a brief description of the production operation(s) and the rationale for the management units be given. Maryland regulations require the reporting of total numbers of plants (by broad plant categories), percent production (per annum), growing area, and production goals (i.e., by time or numbers of plants). This may be most easily reported as a table (e.g., Table 2). For each management unit, it is also important to determine the total number of production cycles per annum (if more than one per year). For greenhouse operations, management units may have multiple cycles being grown in both in the spring and fall seasons.

Nutrient Application (loading) Rates. For each management unit, the total nitrogen:phosphate:potash ($N:P_2O_5:K_2O$) applications are calculated to provide cyclic (and annual) $N:P_2O_5:K_2O$ application totals per hectare (or acre) of growing space (Table 3). These data therefore sum:

- the rate and frequency of application from all nutrient sources (i.e., pre-incorporated, topdressed, soluble, organic, foliar etc.) and,
- the total NPK applied per management unit (kg/ha) or (lb/acre) per production cycle.

The total applied N and P, the frequency of application, and the fertilizer source then provide the data for the management risk assessment process (discussed below).

Irrigation Efficiency and Potential Runoff. The management of water plays an essential role in the nutrient management planning process, since nitrate-N and orthophosphate are soluble. Thus the characteristics of the production site, the irrigation system and irrigation practices are important contributors to the movement of nutrients from the area. Information on the irrigation duration used to water a crop is important in determining the risk of nutrients moving from the production area. Many factors may influence irrigation

Table 2. Sample data table of management unit production data for a hypothetical nursery.

Management unit	Crop	Container size	Number of plants	Growing area (sq m)	Percent area under production	Production time/goal
A1	Annuals	Plugs	100,000	500	1%	Feb–June (2 cycles)
H1	Herbaceous perennial	< 1 gal	75,000	7,500	13%	Mar–Oct (1 cycle)
W2	Woody perennial	1–3 gal	175,000	20,000	34%	6–15 months (1 cycle)
W3	Woody perennial	4–7 gal	150,000	30,000	52%	12–24 months (1 cycle)

Table 3. Sample data table of annual nutrient application totals (kg/cycle per year) for a hypothetical nursery.

Management unit	Pre-incorporated (Osmocote 18-6-12)			Topdressed (CRF) + soluble (20-10-20)			Total (kg/cycle per year)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
A1	—	—	—	136	69	137	136	69	137
H1	205	69	137	114	58	115	319	127	252
W2	205	69	137	68	35	69	273	104	206
W3	295	99	197	68	35	69	363	134	266

efficiency (i.e., size of container, type of substrate, the number of times water is applied per day, and the size and maturity of the crop). A primary goal of this nutrient management process is to manage water applications more accurately and reduce the potential for nutrient leaching and runoff to surface water. Information on container spacing is also important because with overhead irrigation, some water misses the containers and falls directly onto the ground.

The risk assessment process estimates the efficiency of irrigation practices by calculating both the amount of water passing through a container (a measure of excess application) and the amount of water that misses the containers (not intercepted). These two factors are called leaching fraction and interception efficiency. Collectively, these factors combine to produce potential runoff. Both interception efficiency and leaching fraction are influenced by crop maturity and plant architecture, so coefficients need to be developed to adjust for these factors.

Leaching fraction (LF) is defined as the amount of water that runs out the bottom of the container divided by the total amount of water applied to the container, and it is a measure of the excess water applied during an irrigation event. As such, LF is an evaluation of the efficiency of irrigation scheduling practices (duration), and it is evaluated during a normal (timed) irrigation event to determine how much leaching is occurring. Leaching fraction also integrates substrate physical properties, container height (gravitational potential) and irrigation duration.

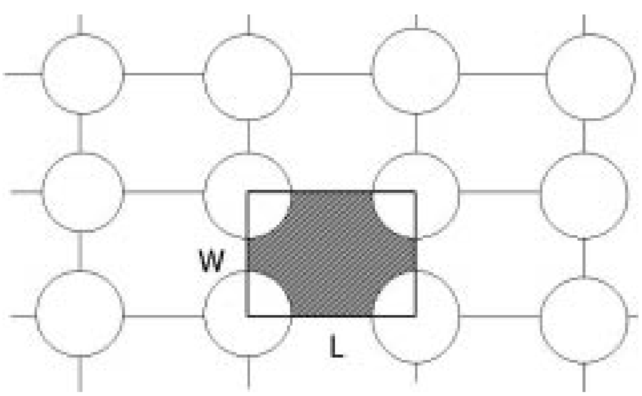

Fig. 1. **Diagram of interception efficiency (IE) with overhead irrigation with a square container spacing. The four quarter circles represent the proportion of irrigation water intercepted by the container (substrate) surface (IE); the shaded area represents the proportion of irrigation water not intercepted by the container area (1 – IE).**

Interception efficiency (IE) is a measure of the amount of applied water that is captured by the container during an overhead irrigation event. Interception Efficiency is usually expressed as a percentage of the applied water, but it can be calculated theoretically in terms of area. Interception efficiency is defined as the container top surface area divided by the ground area allotted to a single container, and is expressed as a percentage value (Fig. 1). Interception efficiency integrates plant density, container size (volume) and irrigation type (method).

Total applied water (TAW) is described as the irrigation water applied during an irrigation event. For risk assessment purposes, this is the maximum daily-applied water for a summer production period. It is used when a volume of water is required for the site risk assessment (see below) or for quantifying the amount of water used. Total applied water can be calculated by:

- using flow meter data;
- multiplying the average nozzle discharge rate by the duration of application and the number of nozzles; or,
- multiplying the average application depth of water (measured by a rain gauge or open container) by the growing area irrigated.

Potential runoff (PR) is defined as the excess water that flows from the growing area being irrigated and moves toward surface water outside of the production area. Potential runoff is the sum of irrigation water not intercepted by the container plus the amount of irrigation water that is leached from the container. Potential Runoff is estimated by the following equations,

Potential Runoff (Volume) =
Total Applied Water × [(1.00 – IE) + (IE × LF)]
or,
Potential Runoff (%) = [(1.00 – IE) + (IE × LF)] × 100,
where IE and LF are expressed as integers.

Potential runoff is obviously reduced by evaporation and/or infiltration, but it illustrates the potential maximum runoff value from any single irrigation event.

Thus for overhead irrigation, runoff is made up of water that leaches through containers plus the water that is not intercepted by containers. The IE value is particularly important in those operations that 'fertigate', (i.e., the application of soluble nutrients in irrigation water). The value (100 – IE) is the proportion of irrigation water or fertigation solution that falls directly onto the ground, which in this case contributes more directly to nutrient runoff than LF. In greenhouse operations, where IE is usually very high (as containers are closely packed) or where drip systems are used, LF becomes

Table 4. Sample data table for average leaching fraction, interception efficiency and potential runoff data for a hypothetical nursery.

Management unit	Crop	Container size	Leaching fraction (LF)	Interception efficiency (IE)	Potential runoff (1 – IE + [LF × IE])
A1	Annuals	Plugs	12%	90%	21%
H1	Herbaceous perennial	< 1 gal	24%	80%	39%
W2	Woody perennial	1–3 gal	26%	60%	56%
W3	Woody perennial	4–7 gal	36%	28%	82%

the most important contributor to the potential runoff (PR) value. Thus, the risk of nutrient leaching in growing operations is weighted either by LF or IE, or both factors when irrigation management is poor and containers are widely spaced (unjammed). Table 4 enumerates the *average* data for each management unit for risk assessment purposes.

When the nutrient application (Table 3) and potential runoff data (Table 4) are combined, an objective estimate of the total maximum daily load (TMDL) of nutrients from that specific management unit can be obtained. This is an important metric, as federal law might require that we move toward calculating these loading rates (5). This data can then be integrated into a site risk assessment of the production area to determine whether existing containment structures, riparian areas or water recycling practices effectively mitigate this nutrient load. In this way, a more complete picture of the potential risk for nutrient runoff may be gained.

Site Risk Assessment Criteria—Contained and Non-Contained Areas. A site environmental risk assessment involves looking at several factors, including the topography, surface conditions, irrigation practices that contribute to water movement and those factors that mitigate the effects of surface water runoff. In the site risk criteria defined by the Maryland out-of-ground regulations (8), containment basins or buffer areas are used to determine the effectiveness of mitigating runoff (Table 5). The current site risk assessment criteria (8) treat containment pond and riparian area as separate entities—the producer can conform to the regulations using either (or both) methods. However, the irrigation and nutrient management portions of this process are designed to reduce water and nutrient loading *before* they reach a containment or riparian area.

Management Unit Risk Assessment. The management unit risk assessment process is used to provide an assessment of the water and nutrient management factors that are unique to each operation. It is essentially a ‘matrix’ of all the factors that can contribute to nutrients moving from production areas. The key variables common to all operations, i.e., leaching fraction, interception efficiency, fertilizer source, N and P application rates, that have been measured (Tables 3 and 4), are now scored against a set of irrigation and nutrient application risk assessment criteria (Table 6). These data are entered into each management unit risk assessment table (Table 7). The risk criteria values in Table 6 represent best management practice estimates that have been developed for Maryland.

Irrigation Risk Assessment Values. Minimum leaching fraction values are based on data from Ku and Hershey (3, 4) and Tyler et al. (9). Interception efficiency data are based on preliminary runoff data (6). Potential runoff values are the mathematical derivative of these data.

Nutrient Risk Assessment Values. The N and P *low risk* data in Table 6 are based upon the following assumptions:

- plant densities range from 5–100 plants/sq m (0.5–9 plants/sq ft) in container nurseries, depending upon container size and placement;

Table 5. Site risk assessment criteria for the container nutrient management planning process in Maryland.

	Zero Risk Risk Factor = 0	Low Risk Risk Factor = 1	Medium Risk Risk Factor = 2	High Risk Risk Factor = 4
A. Contained areas **Complete assessment for growing areas that <u>DO</u> drain to containment Basin.**	Growing area covered; precipitation does not contact substrate AND growing area is on impervious surfaces AND there is total capture and recycling of water	Containment basins sized to hold 90% or more of runoff from maximum daily irrigation; AND some recycling of water from basins; OR some provision (diking, containment, wetlands, etc.) for overflow of basins.	Containment basins sized to hold 90% or more of runoff from maximum daily irrigation; AND there is no recycling of water from basins; AND there is no provision for overflow of containment basins.	Containment basins sized to hold less than 90% of the runoff from maximum daily irrigation
B. Non-contained areas **Complete assessment for growing areas that do <u>NOT</u> drain to containment basin.**	Growing area covered; precipitation does not contact substrate AND Growing area is on impervious surfaces AND there is total capture and recycling of water	Drainage is spread out to sheet flow AND flows through at least 50 feet of vegetation	Drainage is spread out to sheet flow but flows through less than 50 feet of vegetation	Drainage remains channeled to surface water; OR Drainage flows through no vegetation

Table 6. **Criteria for irrigation and nutrient application risk assessment for the container nutrient management planning process in Maryland.**

Variable / Risk	Leaching fraction (LF)	Interception efficiency (IE)	Potential runoff (PR)	Fertilizer source	N Applied (kg N/ha per cycle)	P_2O_5 Applied (kg P/ha per cycle)
Low	< 15%	> 80%	< 32%	Conventional or slow-release	< 350	< 115
Moderate	16–29%	61–80%	33–57%	—	350–700	115–230
High	> 30%	< 60%	> 58%	Soluble	> 700	> 230

- plant densities range from 20 to >2500 plants/sq m (2 to >230 plants/sq ft) in greenhouse production, again depending upon container size and placement;
- general plant N requirements range from 3.5–28 g N/plant (0.125–1.0 oz N/plant) per production cycle.

So, for a plant density of 10 plants/sq m (1 plant/sq ft) for container nurseries and a low plant N requirement of 3.5 g N/plant per cycle, this 'low' fertilization rate equates to a N application of 350 kg N/ha (315 lbs N/acre) per production cycle. Given that P/N ratios (2) range from 0.08 to 0.30 (Table 8), the low P risk assessment values were based on the generally recommended P/N ratio of 0.15 (2), which equates to 500–4500 mg P/plant (0.02–0.16 oz P/plant) per cycle. Thus a low P risk assessment is given for any P_20_5 applications below 115 kg P_20_5/ha (104 lbs P_20_5/acre) per cycle (Table 6). High-risk assessment values were deemed to be applications greater than twice the low risk assessment value. Any N and P application that fall between these two values were deemed to be moderate risk.

Water Recycling Credit. A recycling credit is included in Table 7 as an incentive to those operations that contain and reuse irrigation water. A scale of credits has been proposed whereby points are credited in the risk assessment for the percentage of potential runoff water recycled (i.e., 1%–40% potential runoff water recycled = deduct 5 points; 41%–60% recycled = deduct 10 points; > 60% recycled = deduct 15 points). Thus, an operation with large widely-spaced containers using a high level of overhead-applied soluble fertilizer could reduce their overall risk by containing the runoff and recycling it as irrigation water.

Table 7. **Sample risk assessment for herbaceous perennial management unit H1 from a hypothetical nursery**

Risk factor	Low (= 1)	Moderate (= 2)	High (= 4)	Total
Leaching fraction		2		
Interception efficiency		2		
Fertilizer source			4	
N Application rate	1			
P Application rate		2		
Containment		2		
Riparian buffer width	N/A[z]			
Subtotals	**1**	**8**	**4**	**13**
Percent water recycled[y]				**–5**
Total Risk Assessment Score				**8**

[z]If a factor is not applicable, insert N/A (i.e., no value) for that factor.

[y]There are some factors, such as percentage of water recycled, that are 'beneficial factors.' Points are credited for percentage of potential runoff recycled (i.e., 1%–40% potential runoff recycled = deduct 5 points; 41%–60% water recycled = deduct 10 points; > 60% water recycled = deduct 15 points).

Operational Risk Assessment. The risk assessment values are totaled in the respective management unit risk assessment tables (Table 8 is given as an example). These individual management unit risk assessment tables help the planner or grower identify the higher-risk factors within each management unit. Specific best management practices are formulated to target these higher-risk factors on a management unit basis.

To further facilitate the risk management process, a summary risk assessment table (Table 9) that provides a weighted risk assessment score for each management unit can also be developed for the entire operation. This weighted score is calculated by multiplying the percent area under each management unit by the risk assessment score for that management unit. The weighted risk assessment table (Table 9) is used to indicate what management units give the highest risk *within the operation*. The relative ranking between management units enables the consultant and grower to focus on problematic areas that may need further remedial site risk assessment measures.

Table 8. **Phosphorus/nitrogen ratios for a number of ornamental species. From Handreck and Black (2).**

Plant Species	P/N Ratio
Azalea	0.08–0.15
Boston Fern	0.23–0.25
Carnation	0.07–0.11
Chrysanthemum	0.06–0.17
Cyclamen	0.06–0.08
Cymbidium orchid	0.08–0.10
Dieffenbachia	0.07–0.10
Grevillea	0.11
Phalaenopsis orchid	0.20–0.28
Schefflera	0.08–0.10

Nutrient Runoff Monitoring Procedures. Maryland regulations state that unless an operation is assessed as zero-risk (i.e., completely contained) for nutrient losses from the site, monitoring should be performed on-site (using EC or simple nutrient meters) at those times of the year when nutrients can be expected to be available. The frequency of sampling is determined by the overall risk assessment of each management unit, and areas should be sampled at locations immediately next to growing areas or where runoff from collection basins enters surface water, municipal stormwater, or drainage inlets.

Table 9. Sample summary risk assessment data for a hypothetical nursery.

Management unit	Crop	Container size	Percent production (by area)	Management unit risk assessment	Weighted risk assessment
A1	Annuals	Plugs	1%	8	0.2
H1	Herbaceous perennial	< 1 gal	13%	8	1.0
W2	Woody perennial	1–3 gal	34%	12	4.1
W3	Woody perennial	4–7 gal	52%	10	5.2

Risk Management Recommendations—Best Management Practices. By examining the risk assessment values (from tables 7 and 9), the higher risk management units and the higher risk practices within each management unit can be ascertained. However, the effectiveness of any risk assessment depends upon risk reduction practices and the implementation of those practices. By lowering the assessed value of a particular factor with a set of alternative best management practices (BMPs), the overall system risk is reduced (11). For example, the effects of high concentrations of soluble fertilizers can be mitigated in a number of ways—from reducing the concentration of fertilizer—to reducing the frequency and duration of nutrient application—to adopting a slow-release formulation—or ultimately by containing the leachate and runoff in containment ponds and recycling effluent. However, it may not be economically possible or even necessary to lower the risk of all individual factors, since a matrix of factors is being measured and one factor may have a disproportionate effect on the overall outcome. The flexibility of this risk management process is particularly useful to the grower or manager who must examine the various alternatives, evaluate the economic cost of changes, and determine the practices that must be changed to achieve a reduction in risk.

In summary, finding a simple but rational method for assessing the potential for nutrient runoff is important to maintain the economic viability of the nursery and greenhouse industry. Calculating and evaluating the application rates of nutrients for the least number of management units makes a complex production process manageable. Measuring leaching fraction gives an evaluation of irrigation efficiency, and interception efficiency quantifies the delivery effectiveness of overhead-applied water. Most growers are also keen custodians of the natural environment, and many have been proactive in formulating low-impact methods of producing plants, since these improvements ultimately increase production efficiency and lower costs. Formalizing this process will help everyone ensure that the industry is leading the way to protect the environment.

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