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Ontario's Nutrient Calculator: Overview and Focus on Sensitivity Analysis

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Abstract

The long-term build-up of nutrients in agricultural fields has contributed to surface and ground water quality problems in many jurisdictions. The Ontario government has required the use of a decision support system, entitled NMAN, to develop nutrient management strategies for new or expanding livestock facilities. The NMAN software adds nutrient (N and P) sources (commercial fertilizer, manure, crop residual, grazing) and subtracts nutrients lost through crop removal and runoff to calculate the assimilative capacity on a field-by-field basis. NMAN is designed to help guide nutrient management at the farm-scale and to prevent the long-term build-up of nutrients in agricultural soils. However, success ultimately rests with the farmers' willingness to use NMAN on a continuing basis for determining nutrient application rates. While several factors are shown to influence the use agricultural decision support systems, perceived usefulness or value is key. In an effort to inform users about the NMAN software, we provide a brief description and sensitivity analysis of selected input variables. The newest version, NMAN3, is more intuitive than earlier versions, and it is easier to navigate and to modify parameters. Using a sample nutrient management strategy, we determine the sensitivity of output parameters to changes in the input variables. We primarily focus on the Phosphorus (P) Index, which measures a potential P loss from agricultural fields. The results indicate that the some parameters used in NMAN3, i.e. slope percentage, slope length, etc., need to be accurately measured, and that agency officials should be aware of these parameters during site visits and/or inspections.

Keywords: decision support, NMAN, P index, phosphorus**,** sensitivity analysis

1. Introduction

Over the past 40 years, the agricultural sector has been under increasing pressure to use best management practices to avoid nuisance complaints and environmental impacts. In particular, the livestock industry faces tighter controls on how manure is managed (Centner, 2006). The long-term buildup of nutrients in agricultural fields has contributed to surface and ground water problems in many jurisdictions (Davis et al., 1998; Kang et al., 2008; Blacklock et al., 2010; Winter et al., 2011). Policymakers tend to favour a mix of voluntary, financial and legislative strategies to control agricultural non-point source pollution (Heinz et al., 2002). More recently, decision support tools have become widely available to assist with farm-scale nutrient management (De et al., 2004; Karmakar et al., 2007; Walker et al., 2009). In many jurisdictions, the choice to use an agricultural decision support system is voluntary. However, Ontario's nutrient management regulation requires the use of an agricultural decision support system to prepare a nutrient management strategy. Applications for new or expanding livestock facilities must prepare a nutrient management strategy using the NMAN software prior to receiving a building permit. Once the permit is issued, the nutrient management strategy must be updated every five years. Yet the ongoing use of the NMAN software to guide nutrient management year-to-year is voluntary. Will livestock operators continue to use the NMAN software? Several factors influence the farmers' willingness to use agricultural decision support tools. Batte and Arnholt (2003) found farmers were motivated by hopes of increasing profitability, demonstration projects, identifying in-field variability and reducing risk. Davis et al. (1998) attribute use of decision support tools to the simplicity of use, limited data requirements, suitability for the task, and availability of supporting documentation and technical support. Factors that discourage the use of decision support tools are the need for high quality data and uncertainty concerning decision rules (Gerber et al., 2008). This provides some insight about what motivates farmers to use agricultural decision support tools, as well as factors that dissuade use. The success of the NMAN software ultimately rests with farmers and their continuing use of the NMAN software to guide nutrient management decisions at the farm-scale. The aim of this paper is to inform user groups about the NMAN software through an overview and sensitivity analysis of selected input parameters. A sensitivity analysis can contribute toward validating decision support systems (Gerber et al., 2008).

The paper is divided into four sections. First, we describe the context for nutrient management in Ontario. Second, we provide a description of the NMAN software. Third, the methods and results of the sensitivity analysis are described. Fourth, we discuss the implication of NMAN on the long-term buildup of nutrients in Ontario.

2. Nutrient Management in Ontario

Poor water quality conditions throughout the Great Lakes basin in the early 1970s led to the creation of the Pollution from Land Use Activities Reference Group (PLUARG) to investigate the source of the problem. While point and non-point source pollution strategies showed initial success, recent data indicate total phosphorus levels remain unchanged and even increasing in some areas of Lake Erie (Great Lakes Commission, 2012). With the exception of Lake Superior, the number of algae blooms appears to be on the rise in the Great Lakes (Joosse & Baker, 2011). This is evidence that preventing the long-term build up of nutrients in agricultural soils is a complex problem.

The protection of surface water quality from phosphorus runoff associated with concentrated and intensive livestock operations require effective strategies that address both the rights of individual property owners and the collective interests of the community. Nutrients are essential for the health and productivity of crops. However, the over-application or underestimation of nutrient sources can contribute to surface and ground water pollution. Additionally, the spatial concentration of livestock facilities creates a regional imbalance of nutrients (Sharpley et al., 1999). This spatial concentration can contribute to the over enrichment of nutrients in freshwater aquatic systems that can cause cultural eutrophication, potentially resulting in restricted water use for fisheries, recreation, industry, and drinking (Loague et al., 1998).

The over-application of fertilizers (manure, commercial, and biosolids) or nutrient build-up on agricultural fields is the primary source of excess phosphorus in aquatic ecosystems. In Ontario, policymakers tend to favour a mix of voluntary (e.g. *Agricultural Code of Practice,* 1972), financial (e.g. *Soil Water Environment Enhancement Program*) and legislative (e.g. *Nutrient Management Act* 2006) strategies to influence or control the management on nutrients on a farm. A unique element of Ontario's legislative control is the required use of a nutrient calculator to create a nutrient management strategy to manage manure generated at a livestock facility. Ontario's *Nutrient Management Act R.S.O.* 2002 requires all nutrient generators and receivers to develop a nutrient management strategy or plan. As well, municipal or regional governments have the authority to develop and implement by-laws to protect the health and well-being of citizens; many municipalities have developed nutrient management by-laws. Both the *Nutrient Management Act* and by-laws require new or expanding operations to develop a nutrient management plan prior to receiving a building permit. The requirement of a nutrient management plan helps to ensure there is adequate storage capacity and land area to safely handle the manure generated at the proposed livestock facility.

The Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) developed a decision support tool, NMAN (OMAFRA 2003/2004, NMAN 2.1 released in May 2009) which calculates the agronomic nutrient balance and crop removal balance on a field-by-field basis. It is a mass balance system that adds nutrient sources (commercial fertilizer, manure, crop residue) and subtracts the nutrients lost through crop removal, and overland and through flow pathways to determine if there is a surplus or deficiency in required nutrients for optimal crop production. The estimates of nutrient application rates, crop uptake and removal, and transport processes can be encoded into a computer system to develop a nutrient management strategy. Moreover, NMAN guides farmers or preparers through the requirements to develop a nutrient management strategy. However, farming is often described as both a 'science' and an 'art'. So while agronomy can help determine the necessary conditions for optimal crop growth, traditional management practices also play an important role in influencing nutrient management decisions. This would suggest that for farmers to consider the value of the decision support tool, understanding how the NMAN software operates and a sensitivity analysis is a useful exercise. The sensitivity analysis helps the farmer compare their mental model of nutrient management versus that of the software developers' (Kuhlmann & Brodersen, 2001; Westmacott, 2001). It is important to identify the apparent weaknesses, so they can be identified by those responsible for making adjustments to the system.

Sensitivity analysis (or what-if analysis) involves making changes to model input factors singly or in combinations and determining the resulting changes in the model output factors. Sensitivity analysis results are used to identify the most important model factors, areas for future research, and the level of precision required for measuring system input variables (Kitchell et al., 1977). It is important to distinguish between sensitivity analysis and uncertainty analysis, as these terms are sometimes used interchangeably. Uncertainty analysis refers to the estimation or measurement of input variables or parameters. These values are sampled to determine perspective distributions, to quantify the consequences of the uncertainties in the model inputs (Kleijnen, 1995, 2005). Sensitivity analysis makes no assessment as to the accuracy of the input variables or parameters, only the effect of changing values on the output; it is a "systematic investigation of the reaction of the simulation responses to extreme values of the model's input" (Kleijnen, 1995, 2005).

This article explains and assesses sensitivity analysis in the context of the NMAN decision support system, focusing mainly on the Phosphorus Index. The intent of the Phosphorus Index is to provide indications to minimize the potential transport of phosphorus from agricultural fields to surface water.

3. Sensitivity Analysis

Sensitivity analysis methods can be grouped into one of three categories: mathematical (deterministic), statistical (stochastic), and graphical (Kleijnen, 1995, 2005; Frey & Patil, 2002). Mathematical techniques asses the behaviour of model output based on a range of input factors. These methods include nominal range sensitivity analysis, break-even analysis, and difference in log-odds ratio (Frey & Patil, 2002). Mathematical sensitivity analysis does not evaluate interactions among multiple inputs (Frey & Patil, 2002). Statistical methods assign probability distributions for assessing the sensitivity of input parameters. These methods, which include regression analysis and analysis of variance (ANOVA), evaluate the effect of interactions among multiple inputs. Graphical methods display and complement the results of both mathematical and statistical techniques (Frey & Patil, 2002) in the form of graphs, charts, or surfaces for easier interpretation.

In the current study, a mathematical technique was selected, given the deterministic nature of the NMAN software. In addition, most sensitivity analysis techniques are identified as either local or global. Local sensitivity analyses typically compute partial derivatives of the output factor with respect to the input factors. Global methods apportion the uncertainty in the output factors to the simultaneous adjustment of the input factors. Given that the NMAN software is both linear and deterministic, a local sensitivity analysis method, specifically the nominal range sensitivity analysis, was selected.

Using nominal range sensitivity analysis, one input factor is varied over its entire range of values, while the other factors remain constant. The difference in the output factor (in this case, the P index) due to the change in the input is calculated. The results are ranked in relative order of influence on the output factor.

Assume that the index variables i and j respectively represent a decrease and an increase in the input value I from its nominal value I_0 (with output O_0). Then, the sensitivity index SI for the input variable I and the output variable O is (Loucks & van Beek, 2005):

$$SI = \frac{1}{2} \cdot \left(\frac{|O_0 - O_i|}{|I_0 - I_i|} + \frac{|O_0 - O_j|}{|I_0 - I_j|} \right) \quad (1)$$

A dimensionless expression for SI represents a relative change in the output with respect to a relative change in the input:

$$SI_D = SI \cdot \frac{I_0}{O(I_0)} \quad (2)$$

4. Screening

Screening is the process of sifting though the many required data inputs to identify the most important factors. Several screening methods are available, including group screening (Morris 1987), and sequential bifurcation (de Wit, 1995). However, these techniques are more useful in situations with a large number (> 100) of input parameters or variables, which is not the case with NMAN.

The latest version of NMAN (version 3.2) was released in December 2012, and replaced both versions 2.1 (used to prepare nutrient management strategies and plans (NMS/Ps) and other agricultural nutrient management reports) and 3.1 (used to prepare non-agricultural source materials (NASM) plans). Some features of the software are: choice of English or French language; choice of metric, imperial, or US measures; built-in OMAFRA recommendations; BMP flags; Phosphorus and Nitrogen index calculator; manure nutrient calculator; nutrient balance; economic summary; and estimated soil erosion (Figure 1). In contrast to NMAN2, NMAN3 includes the most current version of ASM (manure) NMAN regulations, manure production and storage calculations (MSTOR), and grazing component and treatment options (e.g. anaerobic digester, composting) (NMAN Software; Brown, 2012).

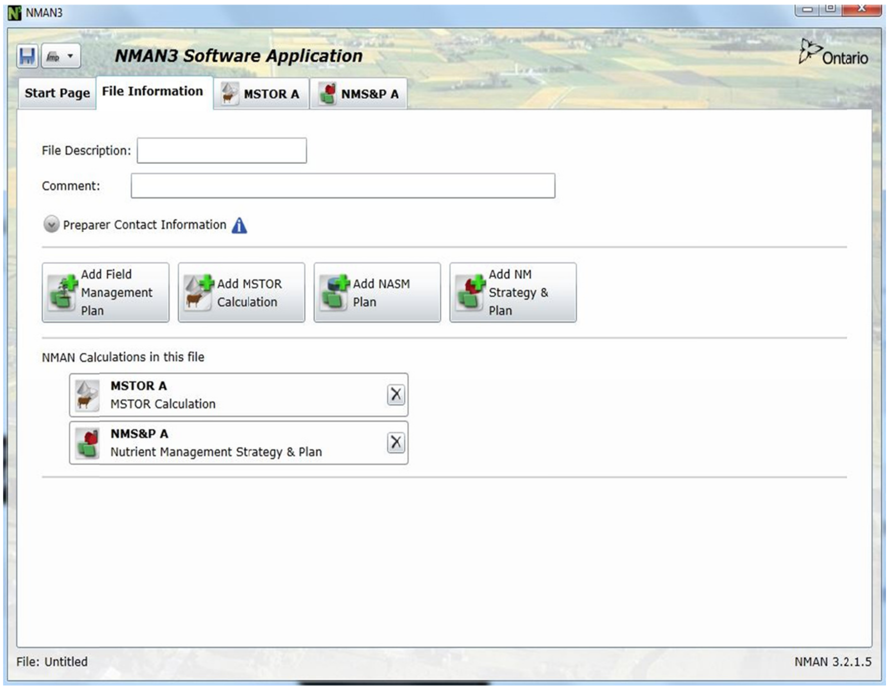


Figure 1. NMAN3 interface: File Information Page

The NMAN package uses a colour scheme to identify when thresholds have been exceeded. The maximum thresholds for the agonomic nutrients balance, and application rates are defined in Ontario 267/03 and programmed in the NMAN software. The A green flag indicates that the value received is within an acceptable range. A yellow flag indicates caution, and is the result of one of three things: additional information or documentation is required, a threshold is approaching, or nutrients could be used in a more economical way. An orange flag means that a specific approval from the Director is required for NASM plans. A red flag indicates there is an environmental concern or violation of the Ontario Regulation 267/03. While a yellow flag (caution) does not require an adjustment by the farmer, a red flag should be addressed as a nutrient management plan may not be accepted.

5. Methods

For the experiments concerning sensitivity assesment, a prototype model farm—the Smithbrook West farm was used for NMAN training purposes, and the base parameters suggested in the manual were entered. Those parameters were: The "West" field is within 150 m (492 ft) of surface water, and contains, or is adjacent to, surface water. This field has 75 tillable acres, 73 acres of which are available for manure application. The maximum field slope used as the base is 5%; the slope near the watercourse in the field is 5%; the slope length is 800 ft; the field has the "Guelph" soil series with a loam soil texture. According to NMAN, this implies soil group B, and runoff potential based on the field slope, 5%, is considered to be low.

The following cropping base information was entered: Crop = *Corn, Grain*; Expected yield = *150 bu/ac*; Tillage Method: *Mulch till*; Cropping/Tillage Practice: *Cross Slope*. For fertilizer application: 3 gal/ac of *liquid starter* ("6-24-6") was applied with the *placed with planter* method. For material application: Material Type: *Swine System: Liquid*; Method of Application: *Tanker*, Incorporation details: *Incorporated in 4 days*; Application Rate: *3000 gal/ac*.

Using these base parameters, NMAN displays agronomic nutrient balance, crop removal balance, the values for the P and N indices, economic summary and trace elements summary. As we concentrated on the P index, the details for the P index calculation for different soil groups B (base), A, C, and D are shown in Table 1.

Table 1. P-Index Calculations for Soil Groups A, B, C, and D

P-Index Factor	**Soil Group A**				**Soil Group B**			
		Value	Weight	Rating		Value	Weight	Rating
1. Soil Erosion	0.27 ton/ac	1	2	2	7.92 ton/ac	2	2	4
2. Water Runoff Class	A, 5% slope	1	1	1	B, 5% slope	2	1	2
3. Phosphorus Soil Test	20 mg/L	2	2	4	20 mg/L	2	2	4
4. Fertilizer App. Rate	10 lb/ac	1	0.5	0.5	10 lb/ac	1	0.5	0.5
5. Fertilizer App. Method	Placed with planter	1	1.5	1.5	Placed with planter	1	1.5	1.5
6. Manure App. Rate	116 lb/ac	8	0.5	4	116 lb/ac	8	0.5	4
7. Manure App Method	Incorporated in 4 days	2	1.5	3	Incorporated in 4 days	2	1.5	3
				16				**19**

P-Index Factor	**Soil Group C**				**Soil Group D**			
		Value	Weight	Rating		Value	Weight	Rating
1. Soil Erosion	7.64 ton/ac	2	2	4	5.37 ton/ac	2	2	4
2. Water Runoff Class	C, 5% slope	4	1	4	D, 5% slope	8	1	8
3. Phosphorus Soil Test	20 mg/L	2	2	4	20 mg/L	2	2	4
4. Fertilizer App. Rate	10 lb/ac	1	0.5	0.5	10 lb/ac	1	0.5	0.5
5. Fertilizer App. Method	Placed with planter	1	1.5	1.5	Placed with planter	1	1.5	1.5
6. Manure App. Rate	116 lb/ac	8	0.5	4	116 lb/ac	8	0.5	4
7. Manure App Method	Incorporated in 4 days	2	1.5	3	Incorporated in 4 days	2	1.5	3
				21				**25**

Soil erosion is a very important factor, with weight 2, in the P index calculation. Adjusting the slope near surface water (%) and slope length (ft) results in large changes in soil erosion estimation and P index values. The sensitivity analysis focused on these two parameters first. They were adjusted for all four soil groups. The slopes used in the analysis were 0%, 1%, 2%, 3%, 4%, 5%, 6%, 8%, 10%, and 12%. The slope lengths ranged from 100 ft to 3200 ft. NMAN automatically displays the runoff potential based on a slope and soil group, and the P index is calculated. For large slopes between 9 and 12%, the runoff potential is very high (see Table 2, OMAFRA Factsheet Determining the Phosphorus Index for a Field, Order No. 05-067, 2005), thereby increasing the P index. The sensitivities were calculated to assess how small, subjective changes in input variables; i.e. slope and slope length, affect the output (i.e. the P index). For example, sensitivity (degree of output change) is computed when the slope is estimated as 5%, but is actually only 4%. The sensitivity indices (SIs) were calculated using Equation 2.

Tillage methods and tillage practices are another foucs of the analysis. These are other important input factors in measuring soil erosion. The base values used in the manual are mulch till/cross slope. Appropriate tillage methods and practices are effective in reducing soil erosion loss. For example, using the mulch tillage method in the fall compared to a conventional fall plow can reduce the soil loss by up to 40%. Also, strip cropping across the slope can reduce soil losses by 50% and even more when using contour strip cropping (compared to up-down slope cropping) (OMAFRA FactSheet 95-089).

The tillage methods used in NMAN are: *plough*, *mulch-till*, *ridge-till*, *zone-till*, *no-till*, and *permanent cover*. The tillage practices are: *up & down slope*, *cross slope*, *contour farming*, *strip cropping – cross slope*, and *strip cropping – contour*. NMAN estimates the soil erosion value, which is highest for the up & down slope practice and plough method. The soil erosion values are then used for the P index calculation.

Using the software, the P index was calculated for the following base values: soil group B and slope length 800 ft. The sensitivity analysis was performed for the tillage methods *plough*, *much-till*, *ridge-till*, and *zone till* (the soil erosion values are the same for zone-till, no-till, and permanent cover). For each of those four methods, the five tillage practices were considered and the sensitivities were calculated for different slopes (0 – 12%) using Equation 2.

Another parameter used for the P index calculation is the fertilizer application method, weighted 1.5. As mentioned above, the base method suggested in the manual is *placed with planter*, *application rate*: 3 gal/ac of "liquid" starter ("6-24-6"). The application methods available in NMAN are: *Placed with planter, Incorporated < 1 day*, *Incorporated 1- 14 days*, *Incorporated > 14 days*, *Not Incorporated*: *Bare Soil*, *Crop Residue > 30%*, and *Standing Crop*. Using these methods, the P index was calculated and the degree of a potential for P movement from the site was determined. Also, red flags encountered when the application rate changes were also observed.

In the P index calculation, the manure application method has a weight of 1.5. NMAN uses the following methods: Incorporated in: *1 day, 2 days, 3 days, 4 days, 5 days; Injected; Not incorporated: Bare Soil, Pretilled, Crop Residue > 30%,* and *Standing Crop*. The base value in the manual was: *Incorporated in 4 days*. The analysis focused on using these methods and also different manure application rate (the manual suggested 3000 gal/ac) to find out if any red flags will be encountered.

The flag summary window would display any red, yellow, or orange flags for the current year. "Amount Remaining" under the Flag Summary is also important, showing whether all the manure produced in a year was spread. This number should be close to 0%, or slightly negative.

5. Results

The P indices were calculated for different soil groups and are displayed on the following figure. The *x*-axis for each of the graphs shows the factor perturbation, calculated as follows:

$$\text{Factor perturbation} = \frac{\text{slope (\%) - base slope (5\%)}}{\text{base slope (5\%)}} \quad (3)$$

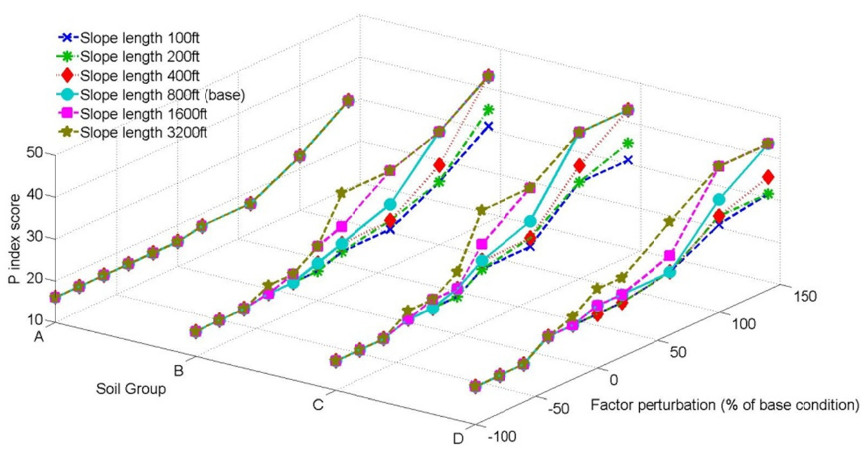


Figure 2. P indices for soil groups A, B, C and D

As expected, the P indices increase as the slopes increase, with values ranging between 16 and 45. The P indices for soil group A (sand) are identical for all slope lengths, as shown in the figure above.

The sensitivity analysis was first performed for soil group B, which was the base input. The nominal input I_0 in Equation 2 was set to the slope 1%, and the base output O_0 was the P index calculated using NMAN3 ($O_0 = 16$). The decrease I_i and the increase I_j in the nominal input was 1%, (i.e. I_i = 0%, I_j = 2%,) and the corresponding outputs calculated in NMAN3 were $O_i = 16$ and $O_j = 16$. The sensitivity index was then calculated using Equation 2, with a result of zero. This result implies that a change in slope from 1% to either 0% or 2% is not sensitive.

Figure 3 shows the sensitivity indices for the slope lengths 0 to 3200 ft. The sensitivities are low when dealing with changes among small slopes. When changing the slope from 5% to 4% or 6%, the sensitivities increase, with the implication that measuring slopes correctly is important. For high slopes 8%, 10% and 12%, and low slope lengths, 100 to 400 ft, the sensitivities are high, as the increase in the runoff potential is higher.

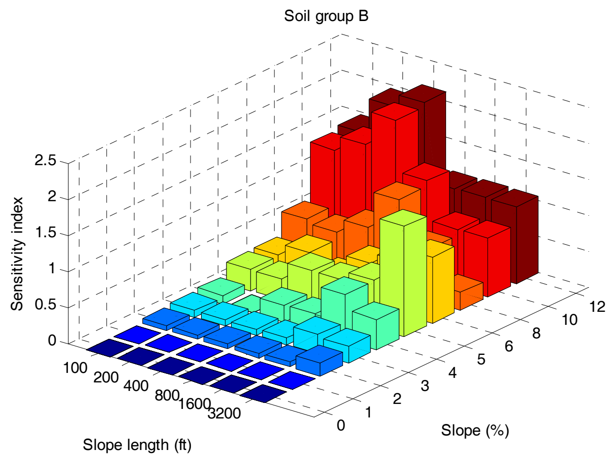
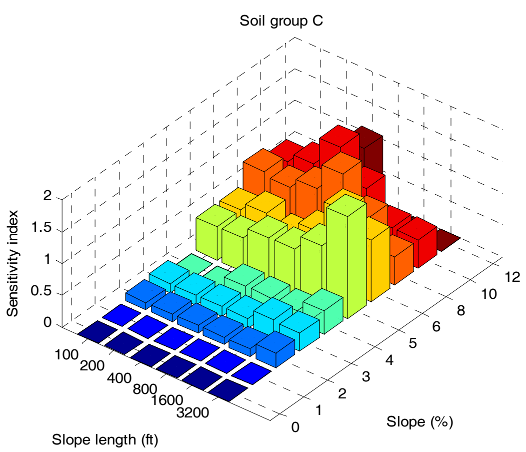
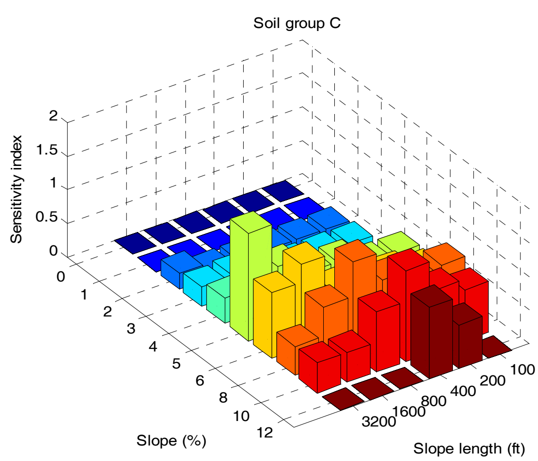


Figure 3. Sensitivity indexes for soil group B, slopes 0 to 12%, and slope lengths 100 to 3200 ft

For soil group C, a similar trend is observed at slope 5%, as sensitivity increases. For slopes 10% and 12%, the P indices for the lengths 100 ft, 800 ft, 1600 ft, and 3200 ft have the same values (33 for 10% and 45 for 12%). Therefore, the sensitivities at 12% slope for those lengths are zero, as shown in the Figure 4.



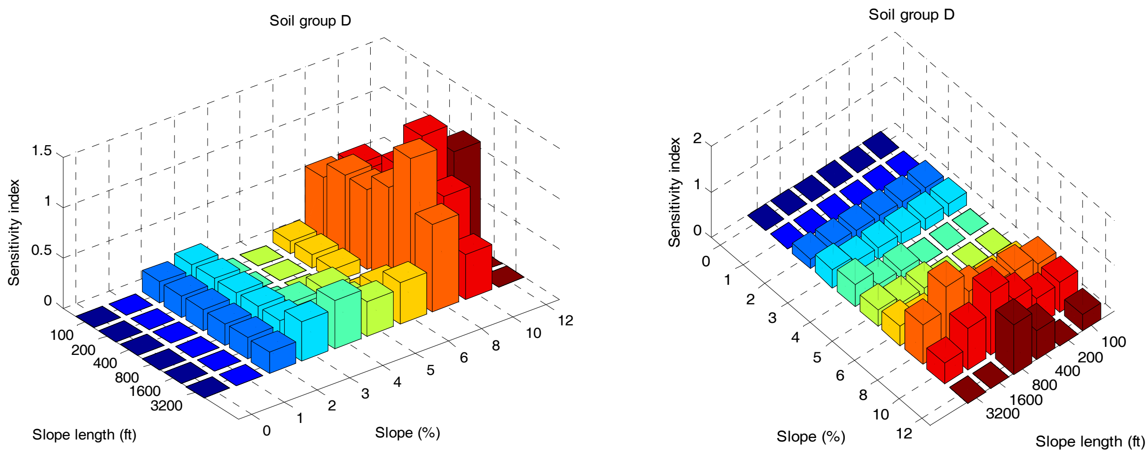
(a)



(b)

Figure 4. (a) Sensitivity indices for soil group C, slopes 0 to 12%, and slope lengths 100 to 3200 ft. (b) Figure (a) rotated for a different view

For soil group D, the slope percentage is less sensitive at 5% than for soil group C. However, sensitivity increases at 8%, with rapidly increasing P index. The sensitivities at 12% slope for lengths 200 ft, 1600 ft, and 3200 ft are zero, as shown in Figure 5.



(a) (b)

Figure 5. (a) Sensitivity indices for soil group D, slopes 0 to 12%, and slope lengths 100 to 3200 ft. (b) Figure (a) rotated

The results for soil group A show an increase in sensitivity indices as the slope increases. For small slopes, the sensitivities are zero as the outputs have the same values (see Figure 6). The sensitivities increase at slopes 6% and 8%.

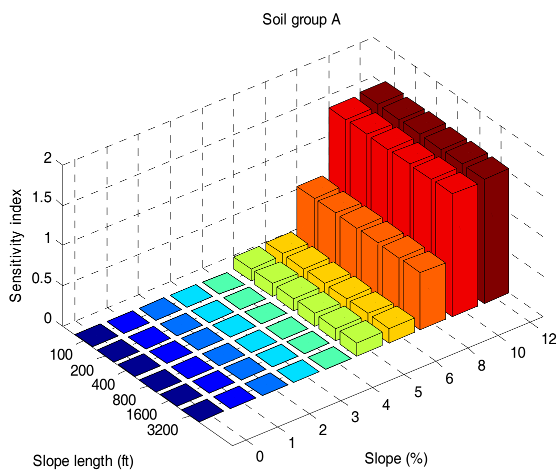


Figure 6. Sensitivity indices for soil group A, slopes 0 to 12%, and slope lengths 100 to 3200 ft

Figure 7 shows the sensitivity indices for the plough tillage method, five different tillage practices and ten different slopes. The sensitivities are low for all tillage practices when dealing with changes among small slopes. When changing the slope from 5% to 4% or 6%, the sensitivities increase for up & down and cross slopes practices. For high slopes 8%, 10% and 12%, the sensitivities are high for all methods and practices, as the runoff potential increases.

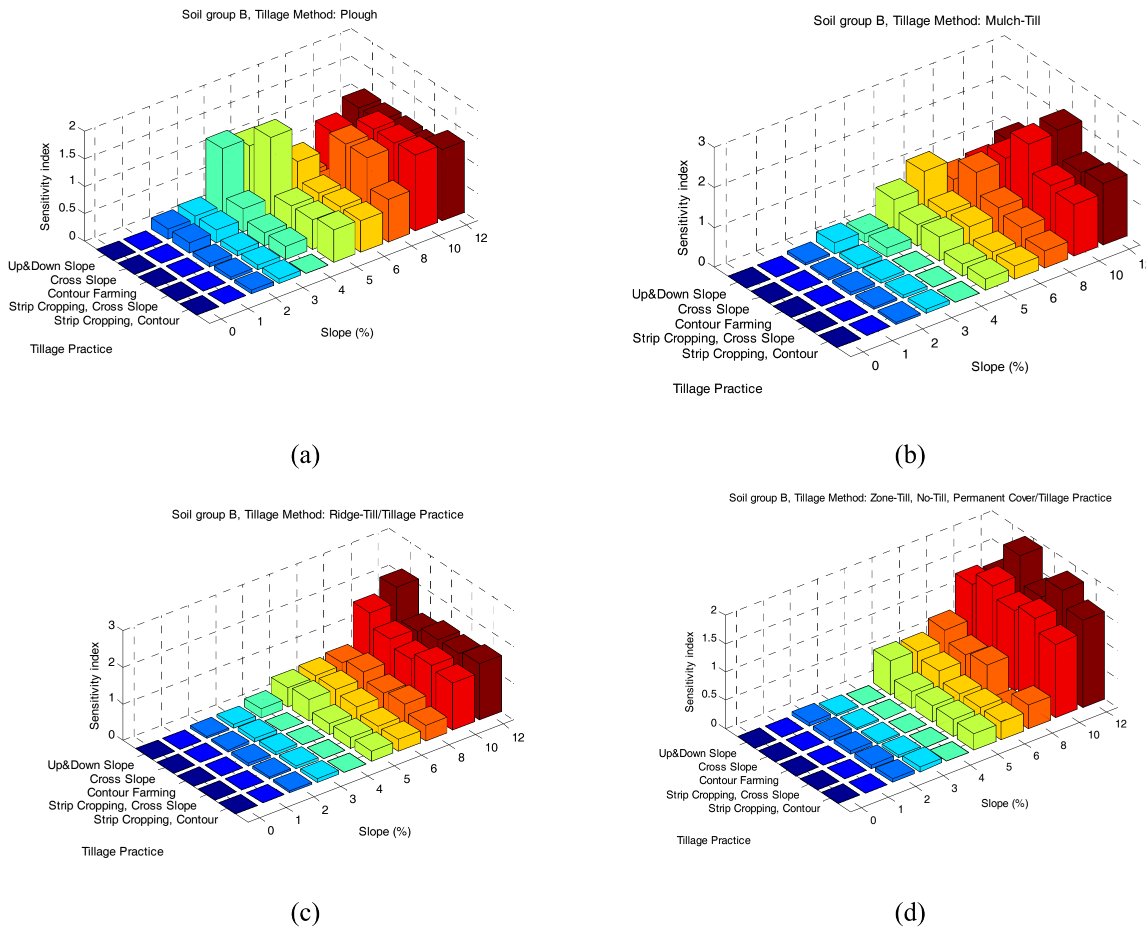


Figure 7. Sensitivity indices for soil group B, slope length 800 ft, slopes 0 to 12%. (a) Tillage method plough, (b) Tillage method mulch-till, (c) Tillage method ridge-till, (d) Tillage method zone-till, no-till, permanent cover

For the mulch tillage method, when changing the slope from 5% to 4% or 6%, the sensitivities increase slightly for up and down, and cross slopes practices; however, are much smaller than for the plough method. Very small sensitivity increase is observed for changing those slopes with the ridge tillage, zone tillage, no tillage, and permanent cover methods as seen on the figures below.

Concerning different fertilizer application methods for the base values of soil group B, slope 5%, and slope length 800 ft, the P index is 19 when *placed with planter*, 21 when *incorporated < 1 day* and *1 to 14 days*, 24 when *incorporated > 14 days*, and 30 when *not incorporated*. The P index value of 30 indicates a moderate potential for P movement from the site. Predicting the length of time before incorpating manure is partly weather dependent and thus uncertain; however, the sensitivy of this parameter is low.

The P indices were calculated for all 10 slopes and five fertilizer methods. The values were the same for the methods not incorporated: *bare soil, standing crop, and crop residue > 30%*. For the slope of 12% and the application method *not incorporated, bare soil*, the P index was 56 which indicates impairment of water quality is high and remedial action is required. Figure 8 shows the SIs for the different slopes and different fertilizer application methods. As seen, the most rapid increase is observed when changing the slope from 6 to 8%. When the suggested application rate 3 gal/ac (liquid 6-24-6) is increased to 6 gal/ac, the phosphate balance exceeds 70 lb/ac in a year, resulting in a red flag.

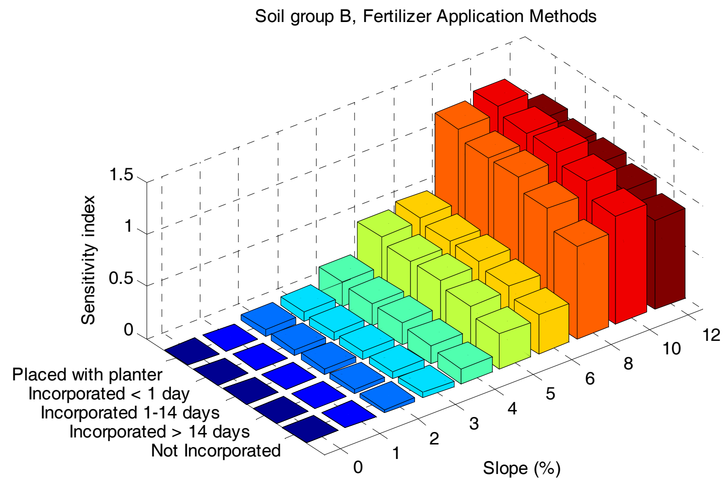


Figure 8. Sensitivity indices for soil group B, slope length 800 ft, slopes 0 to 12%, different fertilizer application methods

Analyzing different manure application methods for the base values: soil group B, slope 5%, slope length 800 ft, and application rate 3000 gal/ac, the P index is 19 for these methods: *injected and incorporated between 1 to 5 days*; 22 for *not incorporated: pretilled, crop residue > 30%, standing crop*, and 28 for *not incorporated bare soil*.

The SIs are shown on the following figure for slopes 0 to 12%. The values are the same for the methods: *incorporated between 1 to 5 days*, and *injected*, and also for the methods *not incorporated: pretilled, crop residue > 30%, and standing crop*. The most rapid increase is observed when changing the slope from 6 to 8%.

When the application rate is increased to 3200 gal/ac and higher, the P index values are the same as described above, however, the phosphate balance exceeds 70 lb/ac in a year, resulting in a red flag.

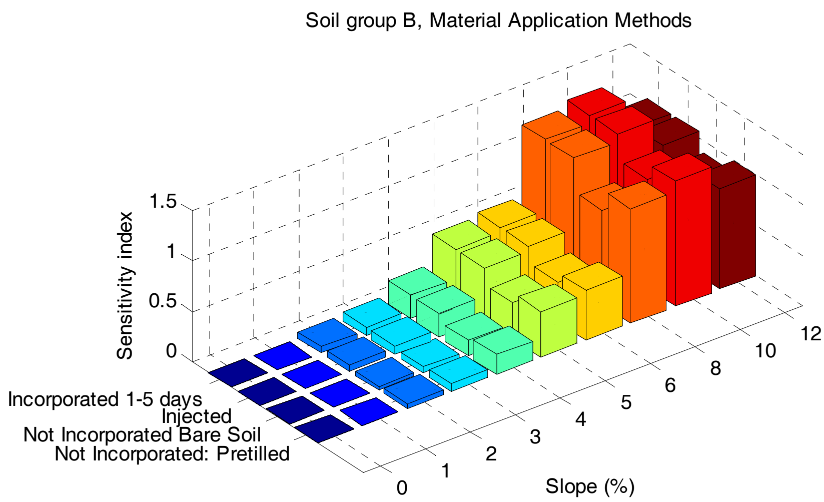


Figure 9. Sensitivity indices for soil group B, slope length 800 ft, slopes 0 to 12%, different material application methods

6. Conclusion

The value of the P index is primarily influenced by soil erosion, phosphorus soil test, water runoff class, and fertilizer and manure application methods. The soil loss value is determined from five factors used in the USLE equation, and these values can be reduced by applying appropriate management strategies, for example reducing the slope length or selecting different tillage methods and support practices.

From the analysis above, it can be concluded that correct estimation of the slope and slope length is crucial in the P index determination. As can be seen in the sensitivity analysis and figures presented above, a small change in a slope may imply a large increase in sensitivity index.

However, actual plans generated by NMAN reveal that changing the slope and slope lengths does not result in changing a plan from being accepted to being rejected. The manure application methods and application rates are the factors that affect acceptance of a plan. For instance, as described previously, increasing the application rate from 3 gal/ac to 6 gal/ac causes the phosphate balance to exceed 70 lb/ac in a year, causing the plan to be flagged for rejection. It is when using these variables that the higher, more sensitive values of slope percentage and slope length play a more important role.

The analysis presented in this paper suggests that variables used in NMAN3 softare are generally less sensitive at low values, and very sensitive at high values. Slope percentage and length, used in isolation, do not have a large effect on outcomes, but must be estimated or measured accurately for higher values, especially when changes to the method of manure application and/or application rates are being considered.

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