A decision support system for field vegetable fertilization

Zdenko Lončarić1,2, Ružica Lončarić2, Ivana Petrošanec1, Dijana Mišević2
Faculty of Agrobiotechnical Sciences Osijek, University of Josip Juraj Strossmayer in Osijek, Osijek, Croatia

Abstract: Decision Support System (DSS) is a computer-supported interactive system, i.e., a software product to assist decision-making at any level of management, with an emphasis on making a directly applicable decision. The purpose of this software for the application in the process of fertilization is to organize and classify data, transform information, and choose how to make decisions and embody them. In its sophisticated form, it is an interactive computer program that uses and integrates a simulation model, a database and a decision model for optimal crop fertilization with different fertilizers. Fertilization recommendations in most countries around the world are based on years of fertilization experiments. When using DSS, the user must enter 3 data groups: 1) the type of vegetable and the planned yield; 2) results of agronomic analyzes (soil pH, soil organic matter content, available phosphorus and potassium, mineral nitrogen); 3) plans for organic fertilization and available fertilizer data. The flowchart of DSS main part consists of 12 steps: 1) determination of target yield; 2) calculating the required amount of nutrient for the target yield; 3) calculating the optimal need of N in fertilization 4) calculating the optimal need of P and K in fertilization 5) determination of optimal organic fertilization; 6) calculation of the timing needed; 7) optimal distribution of N 8) optimal distribution of P and K with respect to fertilization dynamics; 9) the need and plan for application of micronutrients; 10) choosing the optimal form of nutrient and calculating the amount of optimum fertilizers (single and complex) 11) calculation of the nutrient balance 12) calculating the economic effect of vegetable fertilization and growing. DSS groups results into several sets of data: 1) interpretation of the results of agronomic analyzes and soil fertility; 2) recommendation of the quantity of N, P, K and types of fertilizers (required quantities of primary nutrients in mineral fertilization of vegetables, types and quantities of mineral fertilizers required for the mentioned fertilization); 3) balance of primary nutrients, tips and warnings (optimal formulation of fertilizers, the balance of planned mineral fertilization, needs of fertilization with microelements). After receiving the results and guidance, the user simply obtains new output values according to the changes made by simply changing the input data (e.g., to plan a lower yield, other formulation fertilizer, cheaper fertilizer). This mode of operation enables rapid multiple comparisons of the required fertilization with different available fertilizers, on different production sites, and for different target yields and economic effects of vegetable cultivation.

Keywords: NITROGEN UPTAKE, PHOSPHORUS UPTAKE, POTASSIUM UPTAKE, NUTRIENT NEEDS, FERTILIZER FORMULATION, NUTRIENT BALANCE, ECONOMIC RESULT

1. Introduction

Fertilization is an agrotechnical measure of fertilizer application with the aim of achieving high yields, but the impact and the importance of fertilization are significantly more complex in terms of yield quality, soil fertility and sustainable production [1]. Fertilization significantly affects the soil fertility, and thus the yield stability because higher fertility implies a greater ability of the soil to neutralize stress conditions and the adverse effects of insufficient or excessive fertilization. Insufficient nutrient availability is a limiting factor of production and the appropriate fertilization will result in increased nutrient availability and yield. However, if availability is sufficient and is not a limiting factor of production, fertilization will not increase the yield, but may positively affect yield quality. The impact of the added nutrients on the quality of yield depends not only on the quantity and dynamics of the available nutrients, but also on the type and cultivar of vegetables as well as the availability of all nutrients [2]. Furthermore, if nutrient availability has already been optimal, the increased availability through fertilization will negatively affect the quality and may result in reduced yields due to the lower harvest index, leaking, more intense pathogen attack, necrosis, and possible toxic effect of excessive nutrient availability. Fertilization optimization is a complex task due to the simultaneous biological, technological, ecological and economic optimum conditioned by climatic, pedological, physical, chemical and biological factors/agents. Since optimization should be made based on high number of agroecosystems' indicators and simultaneously for different production units, decision support systems (DSS) are most probably among the best solutions [3].

Decision Support System (DSS) is a computer-supported interactive system, i.e., a software product developed to assist decision-making at any level of management, with an emphasis on making a directly applicable decision. The purpose of this software for the application in the process of fertilization is to organize and classify data, transform information, and choose how to make decisions and embody them. In its sophisticated form, it is an interactive computer program that uses and integrates a simulation model, a database and a decision model for optimal crop fertilization with different fertilizers. Fertilization recommendations in most countries around the world are based on years of fertilization experiments.

The aim of this paper is to describe the decision support system based on the results of soil analyses and field experiments in vegetable growing and fertilization.

2. Materials and Methods

The created DSS is based on the results of fertilization experiments which investigated the influence of soil fertility and fertilization on vegetable yield. These include interpretations of soil chemical analysis [1, 5], comparison of different soil nutrient availability analyzes [5, 6], impact of mineral and organic fertilization on nutrient removal and yield in vegetable growing [2, 7], impact of fertilization on soil fertility and nutrient availability [2, 7, 8], impact of liming on nutrient availability and yield [9], and previously created DSS for optimizing vegetable fertilization [3, 10, 11].

First part of DSS is calculation of physiological needs for basic nutrients (N, P, K) required to achieve the targeted yield [2]. Subsequently, physiological needs were adjusted based on soil fertility with the basic principle of increasing fertilization on poor soils and reducing fertilization on fertile soils well supplied with nutrients [1]. This fertilization correction considers not only the level of nutrient availability in the soil, but also the elasticity of the soil, i.e. the ability of the soil to neutralize stress conditions and current changes in soil properties due to fertilization with larger amounts of mineral fertilizers. Also, the correction of the necessary nutrients is carried out with the aim of maintaining soil fertility and preserving the environment [12].

The second part of the DSS refers to the recommendation of the optimal fertilizer and the forms of N, P and K in fertilizers considering dynamics of the required amounts of nutrients and the estimated soil fertility [1, 2].

The last part of the program is a simplified economic analysis of field vegetable growing. The cost structure in the program is done
according to the analyses of the field vegetable production on family farms in eastern Croatia [13, 14, 15]. The economic part of the program consists of yields, prices, variable costs, fixed costs, income and break-even point for every vegetable species. The group of fixed costs consists of accommodation costs, insurance, interest payments and overhead costs related to the machinery management. For machinery amortization costs, insurance and interest payments also are calculated. The total price of aggregate work hour consists of tractor’s costs, related machinery and worker’s wage. It is multiplied by the number of hours (7-8) and what turns out is the financial value of the total cost of aggregate in one shift. This value is divided by the machine effect or norm. This is the final price of machinery in €/ha [16].

3. DSS structure and description

The described DSS uses data on providing information about major nutrients (N, P and K) through a certain vegetable yield, the results of fertilization experiments in vegetable growing [2, 7, 8], the interpretation of the results of agrochemical soil analysis, fertilization recommendations to maintain soil fertility and achieve the target yield as well as elements of the evaluation of the economic effects of vegetable cultivation.

Using the software is very simple. The user enters three groups of data in the left part of the interface (Fig. 1):

1. choosing the type of vegetable, the planned yield, pre-crop, pre-crop fertilization and the achieved pre-crop yield
2. results of agrochemical and physical soil analysis (soil pH, soil organic matter content, phosphorus and potassium available to the plant, residual mineral N in the soil, soil textural class)
3. conducted and planned fertilization with organic fertilizer and available mineral fertilizers.

Fig. 1 Data input for the planned vegetable production

On the right side of the interface there are windows with several groups of new data (Fig. 2):

1. Interpretation of the results of agrochemical properties and soil fertility
2. Recommendation of the amount of basic nutrients (NPK) in the vegetable fertilization with and without the use of organic fertilizers
3. Recommendation of fertilization with organic fertilizer:
   a. the amount of planned organic fertilizer
   b. optimal organic fertilizer according to P / K ratio required in fertilization
4. Recommendation of optimal quantities of available mineral fertilizers for cultivation without the use of organic fertilizers:
   a. optimal formulation of NPK fertilizer
   b. the amount of available NPK fertilizer (in the example shown NPK 7-20-30)
   c. the amount of simple fertilizers (in the example urea and CAN)
   d. main nutrient balance (NPK) as the difference between the need and fertilization possible with available fertilizers
5. Recommendation of optimal amounts of available mineral fertilizers for cultivation with the use of organic fertilizers (optimal formulation of NPK fertilizers, amount of available fertilizers and balance of main nutrients)

**SOIL ANALYSIS** - Slightly acidic soil
   Medium humus content
   (C) Well supplied with phosphorus
   (C) Well supplied with potassium

**ORGANIC FERTILIZATION**:

- Recommend for yield 55 t/ha without organic fertilizer:
  N: 185 kg/ha
  P2O5: 85 kg/ha
  K2O: 120 kg/ha
  Recommend with organic fertilization:
  N: 140 kg/ha
  P2O5: 30 kg/ha
  K2O: 0 kg/ha

**MINERAL FERTILIZATION**:

- Optimal formulation of NPK fertilizer:
  19-17-24
  7-20-30
  413 kg/ha
  Urea 138 kg/ha
  CAN 171 + 171 kg/ha
  Nutrient balance (needs - fertilization):
  0 N -3 P2O5 4 K2O

**MINERAL FERTILIZATION WITH ORGANIC FERTILIZER APPLICATION**:

- Optimal formulation of NPK fertilizer:
  30-13-0
  7-20-30
  75 kg/ha
  Urea 141 kg/ha
  CAN 130 + 130 kg/ha
  Nutrient balance (needs - fertilization):
  0 N -15 P2O5 22 K2O

**NOTE**:

Fig. 2 Output data: required nutrients and the fertilization recommendation.

After getting the results and guidance, by simply changing the data in the left part of the interface (e.g., planning lower yields, planning production on more fertile plots, choosing fertilizer of optimal formulation), after re-pressing the <Calculate> button in the left part of the interface, the user gets new results as output compatible with the changes made. This mode of operation enables a quick multiple comparison of the required fertilization with
different available fertilizers, on different plots and for different target vegetable yields.

3.1. The procedure of calculating the required vegetable fertilization

The procedure of calculating the optimal vegetable fertilization is carried out in 10-12 steps, depending on the soil acidity and the reaction of vegetables to organic fertilization [2]:

1. determining the target yield
2. calculating the required amount of nutrient for the target yield
3. calculating the optimal need for N in fertilization
4. calculating the optimal need for P (P\textsubscript{2}O\textsubscript{5}) and K (K\textsubscript{2}O) in fertilization
5. determining optimal organic fertilization
6. calculating the required liming
7. optimal distribution of N with respect to fertilization dynamics
8. optimal distribution of P and K with respect to fertilization dynamics
9. determining the need and application plan of micronutrients
10. choosing the optimal form of nutrient and calculating the amount of fertilizers (single and complex) in the basic fertilization and top dressings
11. calculation of the nutrient balance (the difference between the determined need for fertilization and the fertilization that is possible with available fertilizers)
12. calculating the economic effect of vegetable fertilization and growing.

1 Determining the target yield

Determining the target yield depends on the genetic potential of the selected cultivar and the vegetable growing system. It is necessary to realistically determine the target yield based on soil fertility and the experience in certain production conditions. After calculating the optimal amounts of nutrients and required amounts of fertilizers, it is possible to correct the set target yield if the soil fertility is not at the necessary level to achieve the target yield (e.g., a large amount of phosphorus or potassium fertilizers should be applied and the soil is too acidic or too light textured so that the application of these fertilizers could be of low efficiency).

2 Calculation of the required amount of nutrients

The calculation of the required amount of nutrients refers to the total amount of NPK that needs to be ensured in order to achieve the target yield and maintain soil fertility, which includes the total amount of nutrients that will be removed from the soil by a given yield and associated residual biological mass. It is also very important that after harvesting or vegetable picking a significant mass that will be decomposed during the vegetation of the next crop, as a result of mineralization or as a consequence of previous mineral fertilization that the pre-crop did not use (e.g. due to lower yields or excessive or to late fertilization with nitrogen). Additionally, N which can be found in the rest of the aboveground mass that will be decomposed during the vegetation of the next crop is also considered available.

3 Calculation of the optimal N need in fertilization

Optimal nitrogen fertilization is calculated on the basis of the total need (physiological needs or removals) for the planned yield. Determined amount of Nmin in the soil, the assessment of mineralization and the available N from organic fertilizer:

\[
\text{Fertilization N} = \text{Physiological need} - \text{Nmin} - \frac{\text{Nimeralization - Inorganic fertilizer}}{\text{Correction}}
\]

4 Calculation of the optimal need for P and K in fertilization

Optimal fertilization with phosphorus and potassium is calculated on the basis of soil phosphorus and potassium availability classes [1]. The basic principle is to enrich poor soils (classes A and B), preserve the availability of nutrients in well-supplied soils (classes C and D) and omit phosphorus and/or potassium fertilization in very well supplied soils (class E) while gradually reducing the availability of nutrients in such soils.

The required amount of phosphorus and potassium in fertilization can be calculated in two very similar ways, using factors [1, 2] or continuous correction functions.

The correction factor depends on the soil supply class and is 0-1.5 for P\textsubscript{2}O\textsubscript{5} and 0-1.75 for K\textsubscript{2}O [1]. Very well supplied soils (class E) have the lowest value (0) and indicate that fertilization with phosphorus and/or potassium in this vegetation is not necessary at all. The highest values (1.5 or 1.75) are for very poor soils (supply class A) and indicate that the soil will be enriched by 50 % more phosphorus or 75 % more potassium than the amount removed by the planned yield. Such an approach allows for the continuous enrichment of poor soils because more nutrients will be introduced into the soil than removed by yield. On the other hand, in soils with the level of available nutrients above a good supply, the amount of available nutrients will gradually, slowly and in a controlled manner decrease.

The estimated annual amount of P\textsubscript{2}O\textsubscript{5} and K\textsubscript{2}O through mineralization of organic fertilizer is calculated in the same way as the amount of N. Thus, 10 t/ha of organic fertilizer with 0.2 % P\textsubscript{2}O\textsubscript{5} (e.g. beef cattle manure) will result in 10 kg/ha of P\textsubscript{2}O\textsubscript{5} in the first, and only 4 kg/ha in the third year. It is clear that the calculation of optimal fertilization depends not only on the planned yield, the specifics of cultivars, agrotechnics of pre-crop, but, above all, on soil fertility.

5 Organic fertilization calculation

The recommendation of organic fertilization is calculated based on the reaction of the selected type of vegetable to organic fertilizers, soil fertility, quality and availability of organic fertilizer. The calculation equation of organic fertilization is a conditional which is not carried out if direct organic fertilization is not suitable for the selected type of vegetables. However, organic fertilization in vegetable production is always useful and almost necessary, either directly for the planned vegetables or for the pre-crop for which an organic fertilizer has previously been applied. The type of organic fertilizer will be chosen based on soil fertility. For example, if phosphorus deficiency is pronounced, the most suitable organic fertilizers will be poultry fertilizers (hen, turkey, chicken, broiler manure) and separated pig manure due to the increased content of phosphorus compared to potassium. The use of cattle manure and horse manure is more suitable on soils with a pronounced potassium deficiency.

6 Calculation of required liming

The need for liming is also a conditional step because it is calculated only for soils whose pH value is too low, and the limit of excessive acidity in vegetable growing can be considered soil acidity below 5.0-5.5. The required liming is calculated in order to achieve the optimal soil pH value, the upper limit is considered to be pH 6.8-7.0. The lower limit depends on the tolerance of the vegetable species to soil acidity. On the so-called organic soils with a higher content of organic matter all types of vegetables tolerate slightly lower pH values due to Al\textsuperscript{3+} cations being less toxic than in mineral soils with a low content of organic matter [17, 18].

7 Optimal distribution of N with respect to fertilization dynamics

...
The optimal distribution of N depends on the type of vegetables (growth intensity, required amount of N, length of vegetation), required amounts of N in fertilization, vegetable growing system, and soil fertility (leaching, denitrification, volatization of the part of the added N). The distribution of N fertilization in all types of vegetables is very important, often crucial for the height and quality of yield. Nitrogen is added for most vegetables, partly by pre-sowing fertilization, and partly by fertigation. Care should be taken as unnecessary excessive fertilization or late fertilization. Fertilization amounts above the optimum do not have to have a negative effect on the yield, but the same yield with less fertilization would be achieved, which means that in order to achieve the same yield, the cost of fertilization could be lower.

8 Optimal distributions of P and K with respect to fertilization dynamics

Mineral fertilizers for most types of vegetables are applied to the soil in the spring, before sowing/transplanting or even together with sowing. For certain types of vegetables, a part of the total required amount of phosphorus and potassium is introduced into the soil by autumn basic tillage, and the rest by pre-sowing fertilization. In the case of vegetables with long vegetation and prolonged fruiting, part of the phosphorus and part of the potassium are applied to the fertilizers along with fertigation systems.

9 Establishing the requirements of microelements and microfertilizers application planning

In soils with unfavorable pH value, micronutrient deficiencies are common. In acidic soils a lack of available Mo and in alkaline Fe, Mn, Zn, Cu and B is expected. It should also be borne in mind that vegetable types differ significantly in sensitivity to or needs for trace elements.

10 Selection of the optimal form of nutrients and calculation of fertilizer quantities

After calculating the quantities and selecting the optimal method of distribution of nutrients, the choice of optimal forms of nutrients and fertilizer formulations remains. The choice of the optimal nutrient form means the choice between the amide, ammonium or nitrate form of N; water-soluble, citro-soluble or less soluble form of phosphate; chloride or sulfate form of the potassium salt; water-soluble or chelated form of micronutrients. The choice of complex fertilizer depends on the ratio of nutrients, but also on the form of nitrogen and the solubility of the phosphate component.

11 Calculation of the predicted nutrient balance

The predicted nutrient balance (the amount of nutrients added to the soil by planned fertilization - the amount of nutrients removed from the soil by planned yield) must be calculated for the reason of advanced (several years ahead) fertilization planning. After calculating the required fertilization for the upcoming vegetation, the planned nutrient balance must be incorporated into the fertilization balance plan for several years ahead in order to maintain soil fertility, but also within the framework of economically viable fertilization. In case of necessary and possible cost reductions, fertilization can be rationalized by reducing the amount of fertilizer or reducing the rates of the application of fertilizer on fertile lands. Namely, in case of one vegetation type fertilization with phosphorus and/or potassium on fertile plots where there is a small need for fertilization with P and/or K can be missed. The obligation to compensate for these nutrients in the next vegetation remains due to the planned fertilization balance.

12 Calculating the economic effect of vegetable fertilization and growing

Calculation of the economic effect of vegetable growing and fertilization is done in the part of model deals with economic issues presenting simplified economic analysis of the field vegetable organic farming. The offered costs are integrated in the program as a help for the user who doesn’t have adequate costs data (mostly for the production profitability predicting). Also, all the amounts, prices or even costs structure or type variable (seed, fertilizers, pesticides, machinery costs, wages etc.) changes are allowed as a new input. Thus, it’s very simple to compare specific production conditions with default model concepts, and to analyze economic importance of site-specific soil fertility, production investments, prices or any other factor. The structure of the most important part of the program, the economic analysis, includes the calculation of total income (TI), variable costs (VC), fixed costs (FC), break even points (BEP) and profit (P). Total income is a sum of income (yield sale amount) and subsidies. Variable costs (VC) are costs which change in accordance with the production volume change. They include: seed or seedlings costs, pesticides, fertilizers, machinery services, fuel, oil and lubricant costs, soil analysis, wages and other (species specific costs). Machinery cost is the sum of related operation cost (listed in model) that is pronounced in prices per hectare (costs of ploughing, fertilizing, pesticides spraying, harrowing, sowing...). Fuel and oil consumption of one’s own machinery is calculated according to the using level, usage effectiveness, specific density, unit price, specific fuel consumption and machinery ages. Lubricant costs are calculated on the basis of annual consumption (2.5 kg/tractor/year, averagely). Wages are product of labor (hours/ha) and average price. Breakeven point of variable costs (BEPVC) as the lowest production efficiency level (where the economic efficiency is zero) is the difference between the total income (TI) and variable costs (VC).

Incomes and variable costs of field vegetables according to the achieved yield and costs are calculated using a model default value. The most significant difference between incomes and variable costs is achieved for tomato, then carrot, pepper and the lowest for white cabbage and Savoy cabbage [4]. Nutrient status changes are described as low, medium and high fertility soil with differences in soil pH (pH = 4, 5, 6, respectively), humus content (1 %, 2 % and 3 %), phosphorus content (10, 20 and 30 mg/100 g P2O5), potassium content (10, 20 and 30 mg/100 g K2O) and Nmin content (0, 25 and 50 kg/ha Nmin). The yield levels are Croatian state average. The most convenient variant is the one with the highest yield on the highest potential fertility soil (the lowest fertilizer variable costs) as expected. Fixed costs (FC) include costs independent of production volume. They are distributed on vegetable species according to sown structure. These costs are the sum of: machinery amortization costs, machinery insurance costs, machinery upkeeping costs, outbuilding amortization costs, outbuilding upkeeping costs, general farm costs, salaries of permanently employed, credit interests, costs of hired agriculture land and insurance premium. Linear amortization method is a part of the model and it includes all farm machinery. Amortization is related only to machinery within proper term use. Profit or loss (P/L) is a final calculation result derived from a difference between total income and total costs: P/L = TI - (VC + FC).

Future improvement of economic fertilization model should include possibility to exchange mineral fertilizers with organic fertilizers. Some of these calculations were conducted implying that the shares of direct fertilizer costs are much more present on less fertile soils due to high nutrient requirements than on fertile soils. Furthermore, the costs of fertilizers participate more in mineral fertilization than the costs of application due to high prices of fertilizers and high performance of their application. The costs of application are the highest in organo-mineral fertilization, because in that case the costs of fertilizer are lower. Economic analysis of different fertilization models has proven the economic efficiency of mineral fertilizer substitution with manure that strongly depends on soil fertility and application costs [2].

4. References

1. Z. Lončarić, K. Karalić, Mineralna gnojiva i gnojidba ratarskih usjeva (Faculty of Agriculture in Osijek University of Josip Juraj Strossmayer in Osijek, 2015)
2. Z. Lončarić, N. Paradiković, B. Popović, R. Lončarić, J. Kanisek, *Gnojidba povrća, organska gnojiva i kompostiranje* (Faculty of Agriculture in Osijek University of Josip Juraj Strossmayer in Osijek, 2015)


8. Z. Lončarić, A. Gross Bošković, N. Paradiković, V. Rozman, Z. Kralik, R. Balčević, V. Bursić, S. Miloš Utjecaj poljoprivrede na kakvoću hrane u pogranicnome području (Faculty of Agriculture in Osijek, Osijek, 2015)


12. Z. Lončarić, A. Gross Bošković, N. Paradiković, V. Rozman, Z. Kralik, R. Balčević, V. Bursić, S. Miloš Utjecaj poljoprivrede na kakvoću hrane u pogranicnome području (Faculty of Agriculture in Osijek, Osijek, 2015)


