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Contribution of the DSS-computer program to wastewater and biosolids reuse in agriculture environment

Prodromos.H. Koukoulakis[1], Spyros S. Kyritsis[1], Guangcan Zhu [2], Ioannis K. Kalavrouziotis[1*]

[1] Hellenic Open University, School of Science and Technology, Aristotelous, Patras, Greece
[2] Southeast University, School of Energy and Environment, 2 Sipailou Street, Nanjing, P.R.China ,

[*] Corresponding author E-mail: ikalabro@eap.gr

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Abstract
The present work deals with the "Decision Support System-Computer Program," a tool that can be used for the reuse of treated wastewater and biosolids in agriculture. It has been developed by the research team of the Hellenic Open University, School of Science and Technology, Laboratory of Sustainable Waste Management. The basic aim of this tool being the following: (a) Exploitation of treated wastewater and biosolid reuse, in agriculture. (b) The safe reuse of treated wastewater and biosolids and optimization of soil fertility and productivity, minimizing human health risk. (c) Improvement of soil physical characteristic by increasing its organic matter content. (d) Rational crop fertilization, suggesting to user the right kind and the optimum levels of fertilizers to be applied to crops and accomplishment of economy in the use of inorganic fertilization of crops. (e) Supply plants with nutrients and irrigation water. (f) Optimize crop fertilization, reducing the fertilizer cost g- forecast and prevent soil pollution with heavy metals. (h) Optimize crop production quantitatively and qualitatively. (j) Protect agricultural soils from over accumulation of biosolids and the surface waters from heavy metals and nutrients. (k) Relieve of the environment from the pressure exerted by the accumulation of heavy metals and toxic substances. (l) Optimize environmental and life quality.

Keywords
DSS, wastewater reuse, biosolids, fertilizer, pollution load index

Introduction

The demographic growth of modern societies, which followed after the end of the second world war, along with industrial, economic and social development, has created some very serious side effects, which have been occupying the mind of many State officials, in relation to finding effective solutions. Among these problems, the environmental pollution has been one of the most important concerns which amongst others includes the mounting amounts of wastewater and sludge that are being produced annually the world over. Today, for example only in USA more than 15,000 wastewater treatment plants produce approximately 150 billion liters of wastewater per day, alone. In addition, septic tanks, serve approximately 25% of the U.S. population, largely in rural areas (Brooks et al., 2012). These quantities create questions as to how to handle and exploit them effectively, and most of all, safely. Thus, one highly attractive option, among the many ways suggested and applied practices in various countries, is the traditional reuse of both the wastewater and biosolids, in agricultural land. This method of reuse is applied not only in low-income countries, but in high income ones, as well. The practice of reuse in agricultural production is very important, because these two efflu-

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ents of the Wastewater Processing Plants (WPPs), supply the soil not only with marginal irrigation reclaimed water and plant macro and micronutrients, but also organic matter, which increases significantly the attractiveness if these inputs and make their effects on the growing plants optimal, contributing to the irrigated agriculture of the dry climate regions, which otherwise would have not been successful. Table 1 shows the typical composition of untreated domestic wastewater. The data of this table refers to raw wastewater so that we can have an idea of the real picture of its composition. Some of the contents reported in the raw wastewater may change during the treatment at the wastewater Processing Plant (WPP). It can be seen that such a wastewater contains considerable levels of macro and micronutrients, but no mention is made of heavy metals. This is because this raw wastewater produced for example in Florida USA, is of domestic (urban) origin and most probably the data of heavy metal concentration is rather very low, and therefore they have been omitted (Brusseau et al., 2019). However, in as much as the wastewater reuse, due to the above reasons, is indeed an excellent option for overcoming the adverse drought effect on crop production in arid regions, at the same time it may as well be very problematic. This is due to the fact that in addition to the favorable characteristics of the wastewater and biosolids, they may also have some important unfavorable attributes being carriers of toxic heavy metals, pathogens(coliforms, streptococci, enterococci, *sigella, Salmonela, Clostridium perfringes, Giardia cysts, cryptosporidium cysts,* Helminth ova and enteric *virus*) emerging pharmaceuticals and microplastics, which may affect adversely the growing plants, the environment, and the human beings subjecting them to serious health risk. Furthermore, these toxic substances may easily enter the food chain via plant uptake and end up in the human digestive system of the consumers causing at high concentration, various serious diseases, including cancer cardiovascular abnormalities and many other unfavorable health conditions (Latip et al., 2022).

Table 1. *Typical composition of untreated wastewater of Florida USA*

Characteristic	Concentration level in mg/L		
	Low	Moderate	High
Total solids	350	720	1200
Total dissolved solids	250	500	850
Volatile	105	200	325
Suspended solids	100	220	350
Volatile	80	169	275
Settleable solids	5	10	20
BOD*	110	220	400
Total organic carbon	80	160	290
COD	250	500	1000
Total elemental N	20	40	85
Organic N	8	15	35
Free ammonia	12	25	50
Nitrites	0	0	0
Nitrates	0	0	0
Total P	4	8	15
Organic P	1	3	5
Inorganic P	3	5	10

(*) Five-day test BOD_5 25^{o}C (BOD biological Oxygen Demand), COD= chemical oxygen demand

Reuse of Wastewater

Despite of all these unfavorable effects, both of these two effluents are being reused in agriculture and in areas of xerothermic conditions, the wastewater being used as an irrigation water and plant nutrient source, and the biosolid as a nutrient and organic matter source, and as a soil amendment factor, which improves soil fertility and productivity. In fact, the reuse of these inputs, is being applied both in developing low-income countries, and also in highly developed regions as well, but more effectively treated. On the other hand, in areas where there is a high scarcity of fresh irrigation water, the wastewater is usually inadequately being treated, and the irrigation of crops, in many cases, may even be done with untreated wastewater to urgently face the irrigation water shortage. Nevertheless, in spite of the treatment inadequacy the wastewater helps the farmers to face relatively effectively the water scarcity. In this relation, it has been reported that that the wastewater shifts the management of these effluents from “treatment and disposal” to the “recycle and resource recovery” and as it is pointed out that the wastewater does not seem to be a problem. but it is part of the solution to challenges, which are faced by modern societies. Furthermore, the wastewater is cost efficient, and a sustainable source of energy, of nutrients, and of organic matter, and all these constituents being related to the production of food energy, security, and health. As there is currently a great concern about the so called “circular economy” the.

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significance of the wastewater seems to increase with the time. This is because there is a great necessity for the protection of natural resources and for environmental sustainability (Unesco, 2017). The increase of the world population further augments the water demands, which become higher and higher with the time. Also, the water needs of the agricultural sector estimated worldwide to 70%, additionally enhance the general water world needs. Similarly, as predicted, more water will be needed for the industrial production as well as for sanitation systems of the expanding urbanization. It is therefore concluded that the future water needs are expected to increase significantly. On the other hand, the intensification of the observed climatic changes are anticipated to exacerbate the special and temporal variations of water cycle dynamics, and the water problems are awaited to occur most probably in relation to discrepancies between "Water supply" and "demand" (Unesco, 2017). It must be underlined that even at the present time the water problems according to the water statistics, are very acute and intensive. Two thirds of the world population, presently is experiencing water scarcity at least once per month as these people live in areas which suffer from drought and water shortage. Also about 500 million people live in regions where the rate of the fresh water consumption exceeds the correspond-ding water resources by a factor of 2 (Unesco, 2017). Thus, the future perspectives of the wastewater seem to be very optimistic in relation to supplementing the fresh irrigation water with wastewater, due to the fact that it is expected that the water scarcity will most probably continue during the coming years, as a consequence of the climatic change. The above water shortage is expected to further be enhanced in the near future by the increased demand for rising agricultural production, due to the expected population increase and extending expansion of cultivated land. In this relation it must be mentioned that in 1961 the area devoted to world agriculture was 1,4 million km^2, and currently is 3.2 km^2 (AQUASTAT, 2014) which are expected to further increase in the near future. The expansion of Agricultural land is obviously leading to additional needs for irrigation water, enhancing respectively the necessity for reuse of wastewaters. Finally, the desertification and nutrient and organic matter depletion of many soils the world over, is expected to strengthen the reuse of the biosolids towards improving their fertility and productivity. Due to the demand for more agricultural commodities, and the water scarcity becoming more severe, characterized by an endless continuity on the one hand, and on the other the ever existing need for the expansion of this irrigated agriculture, farmers are expected to be oriented towards the reuse of non-conventional waters sources, such as reclaimed and some of them of low income countries, they may even use non-reclaimed (untreated)waters to irrigate their crops, thus, facing the water scarcity. According to the present world statistical data related to irrigation water, about 3,028 km^3 of water is withdrawn world per year of which 44% i.e., 1,716 km^3/year is released as wastewater, including both agricultural drainage and waste water, the majority of this water being diverted to agriculture. The municipal demand for water corresponds to only 11% of global water withdrawal. Of this water 3% is consumed and the remaining 8% is discharged as a wastewater, representing 330 km^3 (Mateo-Sagasta et al., 2015), much of which could be used for crop irrigation. Currently, many countries are reusing wastewater in various regions of the world, such as: Middle East, North Africa, Australia, Mexico, China and USA etc. (AQUASTAT, 2014).

Reuse of biosolids

The sludge is a basic byproduct of the raw wastewater processing, which is being subjected to the following treatment procedures, yielding the product, known as Biosolid. Screening: removes the coarse materials which cannot be easily broken down biologically. Thickening: Increases the solid fraction of sludge by centrifugation by approximately 12%.
Dewatering: Increases further the solid sludge content by 20-40% by means of drying beds whereby the high percentage of water contained in sludge (98%) is removed by this process. Conditioning: Separates solid from liquid phase, by the addition of alum or lime or ferric salts or synthetic organic polymers. The final product which is produced by subjecting the sludge to the above procedures, is the biosolid. The sludge is subjected to stabilization process, aiming at reducing its solid fraction, and controlling the pathogens (Brooks et al., 2012). The stabilization processes are made by: a-Aerobic digestion via the supply of air or oxygen to sludge. b-Anaerobic digestion under low redox and low oxygen concentration, aiming at reducing the volatile solids by 35-60% (Bitton, 2010). In USA the biosolids are classified in two classes, i.e. A and B. Class A includes biosolids which result from more

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stringent and enhanced treatment, and contain very low or non-detectable levels of pathogens. On the other hand, class B is the outcome of anaerobic digestion. Land application of biosolids is a popular method of reuse among farmers. It is practiced on the basis of definite guidelines. The concentration macro and micronutrients, as well as heavy metals of biosolids originating from aerobic and lime stabilization of sludge, respectively, are reported in Table 1. The biosolids contain essential plant nutrients and they are very useful as organic fertilizers. They also contain heavy metals as shown in Table 2. These metals are most of them toxic at high concentrations, although some of them (Zn, Cu, Mn) are useful micronutrients, necessary for normal plant growth, but at high concentration they can be toxic. The treated sludge (biosolids) may contain a high percentage of organic matter (10-30%), a very useful synthetic component necessary for the amelioration of the soil physical properties and having a favorable effect on the soil causing coagulation of soil particles, structure formation, water holding capacity, aeration, soil protection from erosion, and water infiltration. The biosolids are very effective in improving skeletal infertile and desertified soils. About 6-to 12 million km^2 world-wide are affected by desertification. Many agricultural soils are inadequately supplied with organic

Table 2. *Major Characteristics of biosolids produced from anaerobically digested, and lime stabilized sludge (Muchovej & Obreza, 2001)*

Characteristics	Type of biosolids	
	Anaerobically digested	Lime stabilized
Solids (%)	25	25
pH	8	12
N (%)	5.6	3.8
P (%)	2.2	1.0
K (%)	0.2	0.4
Cu (mg/kg	566	236
Mo (mg/kg)	23	5
Zn (mg/kg)	1484	321
As (mg/kg)	4	1
Cd (mg/kg)	11	4
Cr (mg/kg)	91	10
Pb (mg/kg)	195	17
Ni (mg/kg)	59	33
Hg (mg/kg)	2	2
Se (mg/kg)	3	1

matter and therefore the application of biosolids is an effective solution to this important problem. Comparing the heavy metal content of biosolids with that of wastewater, there is generally a great difference. Biosolids are carriers of much more higher heavy metal concentration than that of the domestic wastewater, unless the latter is mixed with heavy metal rich industrial wastewaters, which may illegally be diverted into the municipal sewage system. In such cases, there will be a high health risk effect, which must be taken into account. But also, even though the wastewater heavy metals may be at low concentration, if these wastewaters are reused on a long-term basis in agriculture, their heavy metals could accumulate in the on the long run in soil, and this reuse may jeopardize the future safety of the users. In conclusion, the present practice of reuse of both wastewater and biosolids includes a short term or long-term health risk effect, depending on the quality of biosolids or of wastewater, respectively.

In addition to the toxicity problems of heavy metal content of both wastewater and biosolids, these effluents exert a great pressure on the environment when they are not reused. Thus. the reclaimed wastewater is led to the surface waters, and the biosolids are disposed in the courtyard of the WPPs or they are dumped in the landfills, while a very small fraction of them, may be used for the production of organic fertilizers, and other minor uses. In spite of all these vices of the wastewater and biosolids, farmers will continue to reuse these effluents in the future as well, due to their **virtues** which are very useful and supportive of the agricultural production and of the environmental quality. It is hoped that humans will be able to control the above vices, if not absolutely, at least partially, in order to decrease the risk health effect, towards achieving the necessary "safety" of reuse. On the other hand, care must be taken to relieve the environment from the pressure exerted by the annual production of huge quantities of wastewater, and biosolids, worldwide. Considering the fact that currently, the reuse is not only applied in high income countries such as USA, China, and Australia, but also is much needed in countries suffering from drought, to the extent that the wastewater is even used untreated, such as in Pakistan (Ensink, 2002), in India (Bradford et al., 2002), in Bolivia and Ghana (Huibers et al., 2004).

Obviously, with the further increase of the word population, and the expected intensification of climatic changes, the reuse will be more necessary in

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the near future. Therefore, the prospects are that the reuse will continue to “reign” in the future. Consequently, it is necessary that there must be found a way to achieve the “reuse safety” to protect both the users and the environment as well as the growing plants from the health risk effect of the heavy metal toxicity. Meeting this international problem is a “sine qua non” condition. Some relevant methods for facing this serious problem are as follows:

- the indirect reuse.This method can be applied in wetter climate by discharging the wastewater into the fresh water stream, provided that there will be available such a stream, where the former is diluted and can be used for crop irrigation. This procedure is applied in by the downstream users in India, Brazil, Argentina, Colombia (Jiménez & Asano, 2008; Keraita et al., 2008; Raschid-Sally & Jayakody, 2009).

- the planned used reclaimed water. Applied more frequently in countries of higher income where the motivation is the water scarcity and in countries N. America, Australia, Mediterranean countries and USA (AQUASTAT, 2014). Use of a Decision Support System - computer program seems to be a promising method for facing successfully not only the health and accomplishing a series of advantages which will be mentioned below.

The scope of the decision Support System

The basic aim of the DSS-computer program (DSS-CP) is summarized below as follows:

- to help reduce the health risk effect of heavy metals on humans;
- to succeed the rational reuse of wastewater and biosolids in agriculture;
- to protect the environment from the accumulation of heavy metals.

The DSS also aims at more targets, which will be mentioned in the coming pages. More specifically, the DSS aims at integrating all related issues to sustainable reuse, providing useful support for solving, as much as possible, within the existing possibilities, the problem of addressing the safe wastewater and biosolid reuse. In other words, the DSS provides a compendium for the selection of the most suitable method, relevant to address problems related to the management, operation and design of the DSS program. Actually, the DSS is a comprehensive tool, which can integrate several data and multicriteria perspectives, with the view to lead to more variable results. Referring to wastewater and biosolids, the DSS is oriented to more sustainable solutions for their management. These effluents of the Wastewater Processing Plants (WPPs), can be used for crop irrigation and fertilization, respectively, of agricultural crops, as well as for soil improvement. The practice of their reuse is related to a number of environmental issues, such as soil pollution with heavy metals, and plant toxicity. The relevant question arising at this point is: How to overcome this adverse effect, so as to make the wastewater and biosolids more friendly to the environment. The basic requirement is to achieve the following: i.e.to reuse wastewater and biosolid as safely as possible, targeting at protecting the users, and the environment of the agroecosystem from heavy metal pollution, as well as from other toxic substances, such as from the emerging pharmaceutical compounds, whose control at the present time is not so easy to attain, due to the high cost and the lack of pharmaceuticals critical values. However, the accomplishment of rational fertilization of crops could help to relieve the environment from the pressure of the accumulation of the biosolid heaps on the grounds of the WPPs, and to stop diverting the produced treated wastewater into the water bodies (sea, rivers etc.), a practice that is applied in regions which for the time being provide plenty of natural fresh water for the irrigation of their crops.

The need for DSS-computer program

In order to achieve the abovementioned goals, there is an urgent need for a special DSS- computer program, that is for an effective tool, that will be capable to accomplish the “safe reuse” of the treated wastewater and biosolids. The DSS is basically a computerized program, used to support the determination, judgements and courses of actions in a given system or organization. The DSS shifts through, and analyzes massive amounts of data, compiling comprehensive information, used to successfully solve problems in the decision making, in regard to succeeding set of targets. Thus, according to the above mentioned, a DSS is a computerized system that processes data, synthesizes them aiming at producing comprehensive information. In short, the DSS gives the possibility for more information decision making, solving timely the problems and offering improved efficiency to related issues, planning effectively operations helping the accomplishment of the productive management. Another capacity of the DSS- computer program is that it integrates all the multiple variables and produces an outcome based on the conducted reche-

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arch and especially on current research conclusions. The target of the DSS- computer program is to protect the biological life be it human or animal or plants, aiming at accomplishing the mostly desired "safety of the reuse". To accomplish these multiple targets a DSS compu-ter program has been built and designed by the rese-arch team of the Laboratory of Sustainable Waste Management, Hellenic Open University, which is ca-pable of compiling all those variables involved in the effective function of this DSS –Computer Program, with the following Capabilities (Koukoulakis et al., 2020):

- to help in the safe reuse od treated wastewater and biosolids and optimize soil fertility and productivity minimizing human's risk;- to improve soil physical characteristic by increasing its organic matter content;
- to guide the user about the rational crop fertilization, suggesting to user the right kind and the optimum levels of fertilizers to be applied to crops;
- to Supply plants with nutrients and irrigation water;
- to optimize crop fertilization, reducing the fertilizer cost;
- to forecast and prevent soil pollution with heavy metals;
- to optimize crop production quantitatively and qualitatively;
- to protect agricultural soils from over accumulation of biosolids and the surface waters from heavy metals and nutrients;
- to relieve the environment from the pressure exerted due to accumulation of heavy metals and toxic substances:
- to optimize environmental and life quality.

Additionally, the DSS-CP is capable of accomplishing the following:

- it can calculate the optimum nutrient dose for each separate kind of crop;
- estimation of the nutrient inputs contained in the soil as residual nutrients:
- calculation of the optimum rate of soil liming material;.
- it can calculate the nutrient losses due to leaching, denitrification, fixation and removal by the crop harvest;
-it can calculate the quantities of the available inorganic nutrients contained in the soil, the wastewater and biosolids;
- it can calculate the possibly additional fertilizers that must be needed to be added. to the soil in the case that the nutrients supplied by the soil cannot satisfy the needs of the growing plants;
- it can guide the users as to the time, quantity, and method of application of the advised additional inorganic fertilizers;
- it can calculate the heavy metal pollution indices of the soil and prevent further pollution of the soil and crops;
- it can control the quality of the wastewater that is to be used for the irrigation of crops and to exclude it in case it is not in agreement with the international standards;
- it informs the user about the level of soil salinity to take the necessary measures.

Evaluation of credibility of the DSS-computer program

The accurate function, and credibility of the DSS-Computer program (DSS-CP) will be examined below by evaluating the statistical relationships of its outcomes i.e. internally decided advices given by the DSS-CP, related to the results obtained externally, under real environmental conditions, based on experimental data. To document the credibility of the DSS-CP, i.e., the effect of the advised nitrogen *(N_{dose})* levels for application to ryegrass, on fresh green plant matter production, under treated wastewater and biosolid, was studied (Figure 1). It was found that the advised by the *DSS-CP levels of* N_{dose} were related negatively but statistically highly significantly with the ryegrass green matter (biomass) produced. The application of treated waste water, and biosolid increased the N soil content, possibly creating a salt effect at the expense of plant growth. Thus, based on Figure 1, maximum green matter of ryegrass yield can be obtained at 240-250 kg N/ha. This level seems to be very logical as the ryegrass is relatively a high N consuming crop. The important finding in this case is the very good significant fit of the internally determined N_{dose} with the external fresh green matter yield of the ryegrass studied, with the R being 0.872 and level of significance <0.001. To further document the evaluation of the credibility of DSS-CP, the effect of the N_{dose} was examined by relating it with ryegrass plant height (Figure2). As shown in Figure 2, this relation is quadratic (curvilinear), antagonistic and statistically significant (R 0,870), with the level of significance being <0.001) showing a tendency similar to the effect of N_{dose} on the fresh green matter yield of Ryegrass (Figure 1), under the same treatments of treated wastewater and biosolids. This perfect similarity shows undoubtedly the statistically significant relation between the inter-

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nal function of the DSS-CP i.e., of the determined N_{dose} with the external variable i.e., the fresh green en matter production, reflecting an excellent and accurate DSS-CP function.

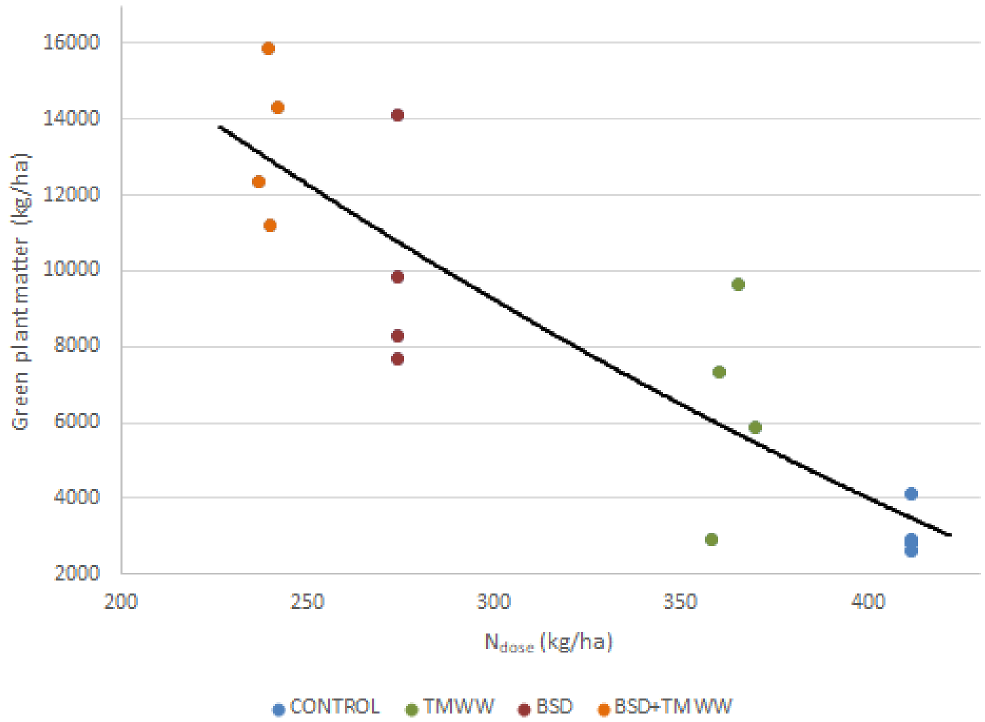

Figure 1
Effect of application of DSS-CP advised nitrogen levels (N_{dose}) on ryegrass fresh green plant matter production, under treated wastewater and biosolid, treatment

$$GreenPlantMatter = 0.058 \times (N_{dose})^2 - 92.516 \times N_{dose} + 31803.120,$$
$$R = 0.872, \quad Sig. < 0.001$$

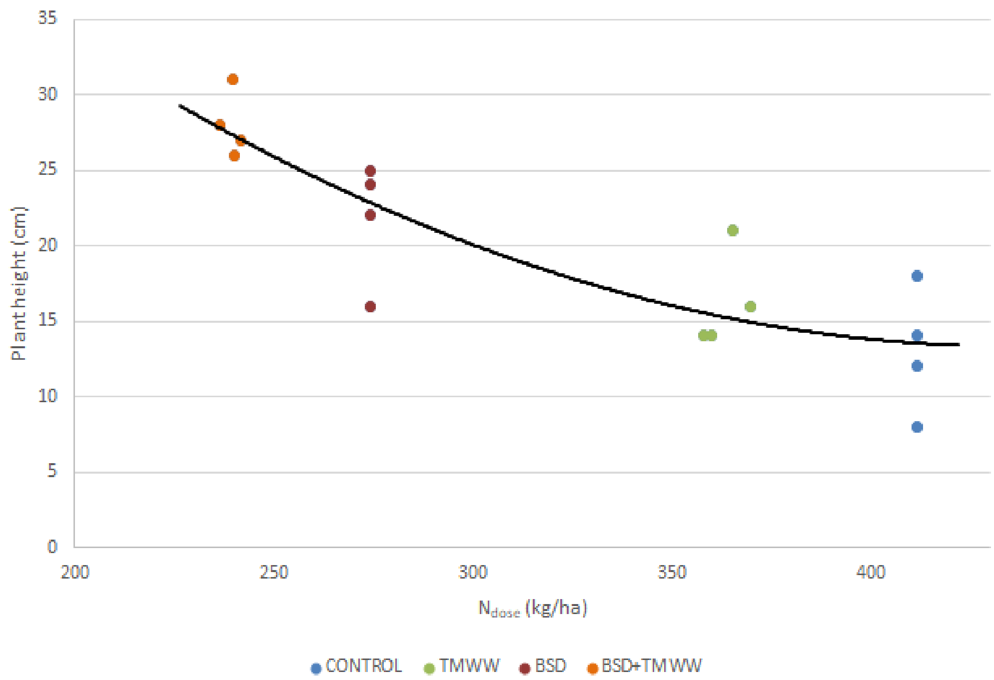

Figure 2
Effect of application of DSS-CP advised nitrogen levels (N_{dose}) on ryegrass plant height, under treated wastewater and biosolid, treatment

$$PlantHeight = 0.00036 \times (N_{dose})^2 - 0.315 \times N_{dose} + 82.07,$$
$$R = 0.870, \quad Sig. < 0.001$$

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Furthermore, to strengthen more effectively the credibility of this DSS-CP, the effect of total available soil nitrogen (TAVN) on fresh green mater yields of Ryegrass was investigated (Figure 3). This relation is indeed very important as it shows the capacity of the internal function of the DSS-CP to control the various soil plant nutrients, such as N, P, K, etc. and their multiple sources, as well as their losses, so as to lead the N to the growing plants. The TAVN originates from many soil sources, such as most important being the organic matter, residual soil nitrate, and ammonium, treated wastewater, biosolids and atmospheric N, while the N losses include the following: leaching, fixation of ammonium-N, denitrification, harvest N removal and immobilization by microorganisms (Koukoulakis et al.2000). The DSS-CP is capable of exploiting all these N sources of contribution and of losses, so that it can calculate the total available N or of any other plant macronutrient, and advise the relevant nutrient dose for application to the growing crops.

The highly statistical significance (R0.873 and significance <0.001) of the studied effect of TAVN on ryegrass fresh green matter under the treated wastewater and biosolid treatment, showed that the DSS-CP functions accurately and can be considered a credible tool for the reuse of these effluents in agriculture.

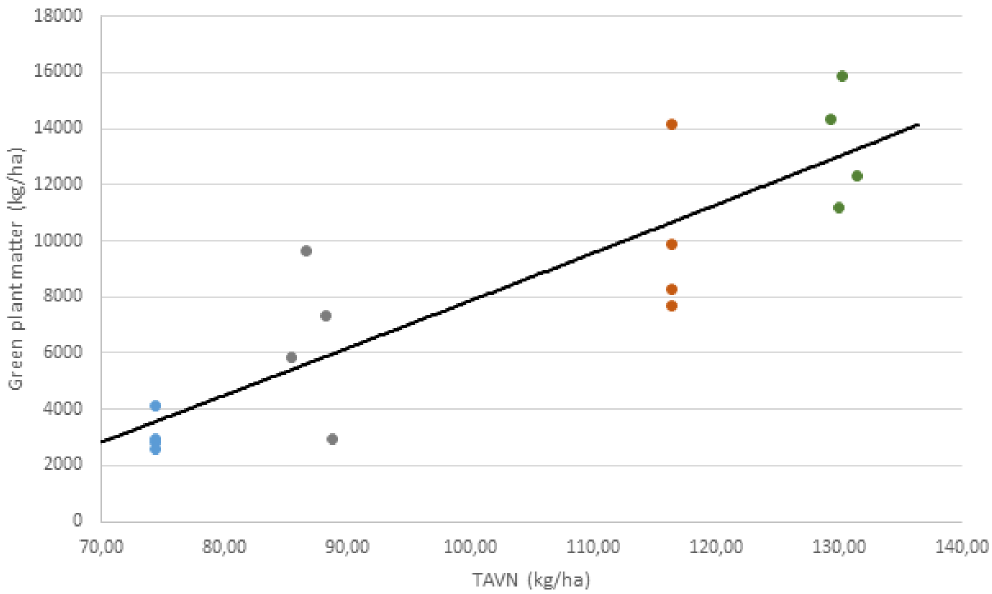

Figure 3
Effect of DSS-CP calculated total soil available nitrogen (TAVN) on fresh green matter of ryegrass production, under treated wastewater and biosolid, treatment

$$GreenPlantMatter = 0.062 \times (TAVN)^2 + 157.393 \times TAVN - 8493.88,$$
$$R = 0.873, \qquad Sig. < 0.001$$

Another relation between DSS-CP determined total available N (TAVN) with the ryegrass plant height (Figure 4), was also examined. It was found that the above relation was exactly similar in trend and in accuracy as well as in relation to statistical significance with that of Figure 3. In other words, according to Figure 4, the effect of TAVN on plant height is expressed by a quadratic model, positive (synergistic) and statistically significant. This trend is similar to that relating TAVN with ryegrass fresh green matter (Figure 3). Both of these figures show the same trend, a fact that emphasizes the credible function of the DSS-CP.An important relation between the DSS-CP determined TAVN with DSS N_{dose} determined for the rational fertilization of ryegrass (Figure 5), showed that these two variables are related statistically significantly and negatively. This means that with the increase of the TAVN level the N_{dose} decreases. A logical result because since the soil TAVN increases, it is logical that for the DSS-CP to respond negatively; i.e., to decrease the level of the advised N_{dose} to be applied to the growing crop. Any other response would have been mistaken. These results show that the DSS- CP can adjust itself accordingly under such situations. Since both of these interacting variables i.e. N_{dose} and TAVN are internally calculated by the DSS-PC, they show an excellent fit with the R being 1.00, and the level of significance <0.001 (Figure 5).

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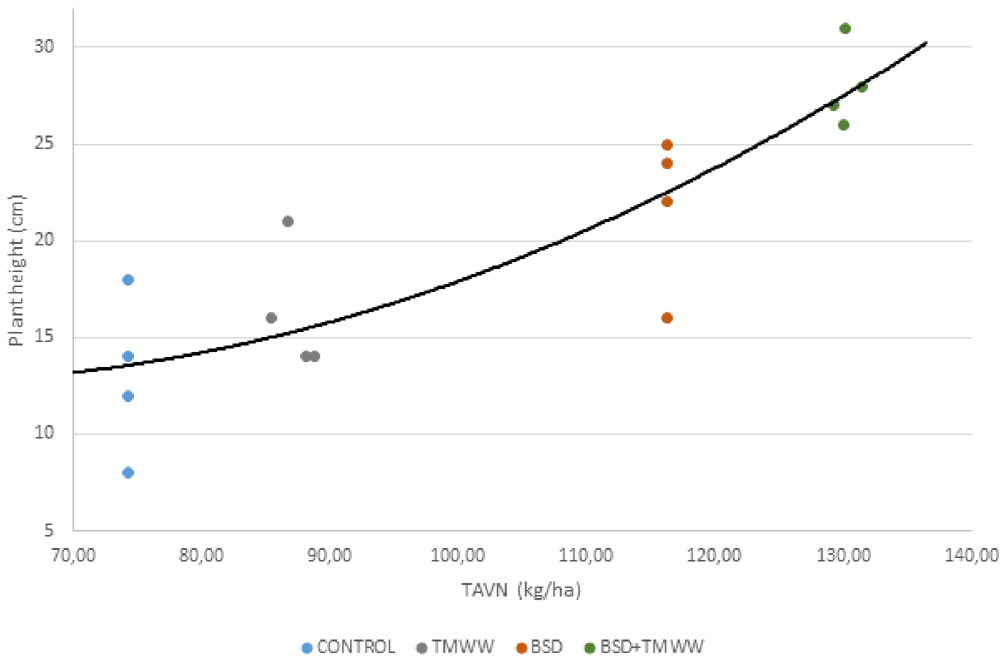

Figure 4
Effect of DSS-CP calculated total soil available nitrogen (TAVN) on plant height of ryegrass production, under treated wastewater and biosolid, treatment

$$PlantHeight = 0.003 \times (TAVN)^2 - 0.303 \times TAVN + 21.137,$$
$$R = 0.874, \qquad Sig. < 0.001$$

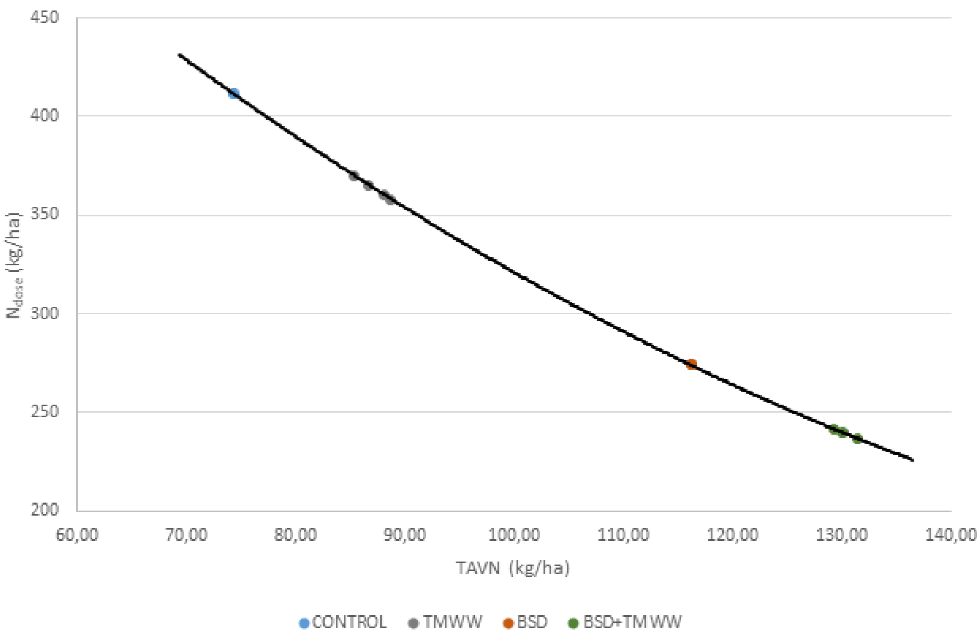

Figure 5
Effect of DSS-CP calculated total soil available nitrogen (TAVN) on the advised nitrogen levels (N_{dose}) for the rational fertilization of ryegrass crop under the treated wastewater and biosolid, treatment

$$N_{dose} = 0.003 \times (TAVN)^2 - 0.303 \times TAVN + 21.137,$$
$$R = 1.000, \qquad Sig. < 0.001$$

Similarly, the credibility of the DSS-CP was also based on the relation of total available gain of nitrogen (N_{TAgn}) suggested by the DSS-CP with the ryegrass green matter yields, and also with the plant height (cm), respectively. The N_{TAgn} is expressed as a function of total available nitrogen (N_{TAVN}) calculated by the following relation [1]:

$$N_{TAgn} = \max N_{TAVN} - N_{TAVN} \qquad [1]$$

The results of the above relation are reported in Fi-

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gure 3 and 4 for green plant matter and plant heights, respectively. Also the credibility of the DSS-CP was evaluated on the basis of relation between N_{gain} with the ryegrass green matter yields, and with plant height (cm), respectively. The N_{gain} is expressed as a function of N_{dose} i.e. of the optimum N level advised by the DSS-CP and calculated by the relation [2]

$$N_{gain} = maxNdose - Ndose \qquad [2]$$

The results of the above relation, obtained, are reported in Figure 6 and 7 for the green matter and plant height, respectively. The study of the Figure 6 shows that the N_{gain} levels advised by the DSS-CP, are highly statistically significant related to the ryegrass green matter, suggesting that the function of the DSS-CP is accurate and credible. Furthermore, it reveals a high degree of credibility, suggesting that the function of the DSS-CP is producing results which are in line with all the above results. Additional support, related to the credibility of the DSS-CP is also found in the relation between The N_{gain} and plant height (Figure7). As expected logically, the DSS-CP being in line with this logic, shows that the above relation depicted in Figure 7, is indeed positive, and statistically highly significant (<0.001), proving that there is a close and strong relationship between the internal function i.e., the N_{gain} calculation, and the external processes, like that which characterizes the production of ryegrass biomass yields.

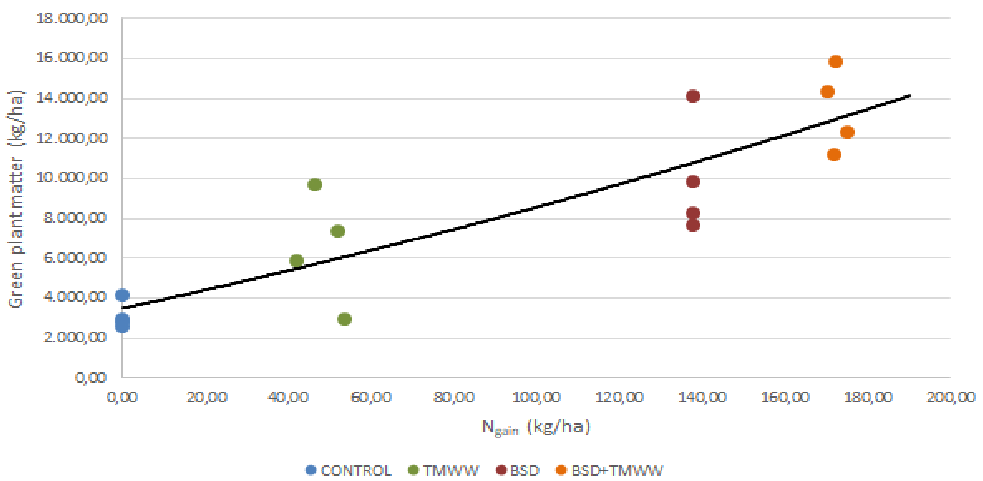

Figure 6
Effect of DSS-CP advised nitrogen gain (N_{gain}) on ryegrass fresh green plant matter production, under treated wastewater and biosolid, treatment

$$GreenPlantMatter = 0.058 \times (N_{gain})^2 + 45.074 \times N_{gain} + 3470.042,$$
$$R = 0.872, \qquad Sig. < 0.001$$

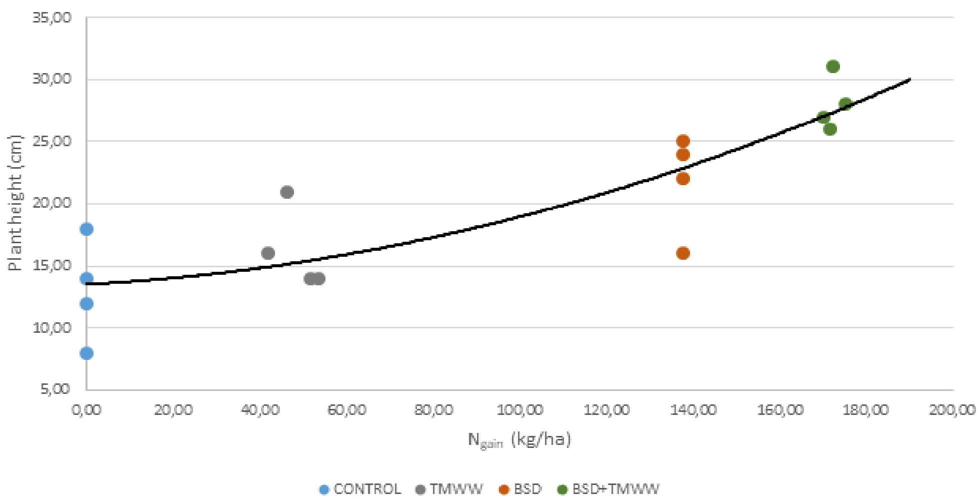

Figure 7
Effect of DSS-CP advised nitrogen gain (N_{gain}) on ryegrass plant height, under treated wastewater and biosolid, treatment

$$PlantHeight = 0.00036 \times (N_{gain})^2 - 0.018 \times N_{gain} + 13.53,$$
$$R = 0.870, \qquad Sig. < 0.001$$

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Last, but not the least, according to Figure 8, the relationship between the N_{gain} and N_{dos}i.e., the advised N levels by the DSS-CP, is similarly statistically signifycant at a level of p<0.001. It is however negative, suggesting that with increase of the nitrogen presence in the soil, the corresponding advised nitrogen levels (N_{dose}) by the DSS-CP decreases significantly. .Obviously, these results are in a perfect line with the reality. That is, since more N is supplies the soil, it is natural that the advised N_{dose} will decrease. It must be under-lined at this point, that the DSS-CP acted logically and effectively, proving its undeniable credibility, which is also statististically highly significant(<0.001)

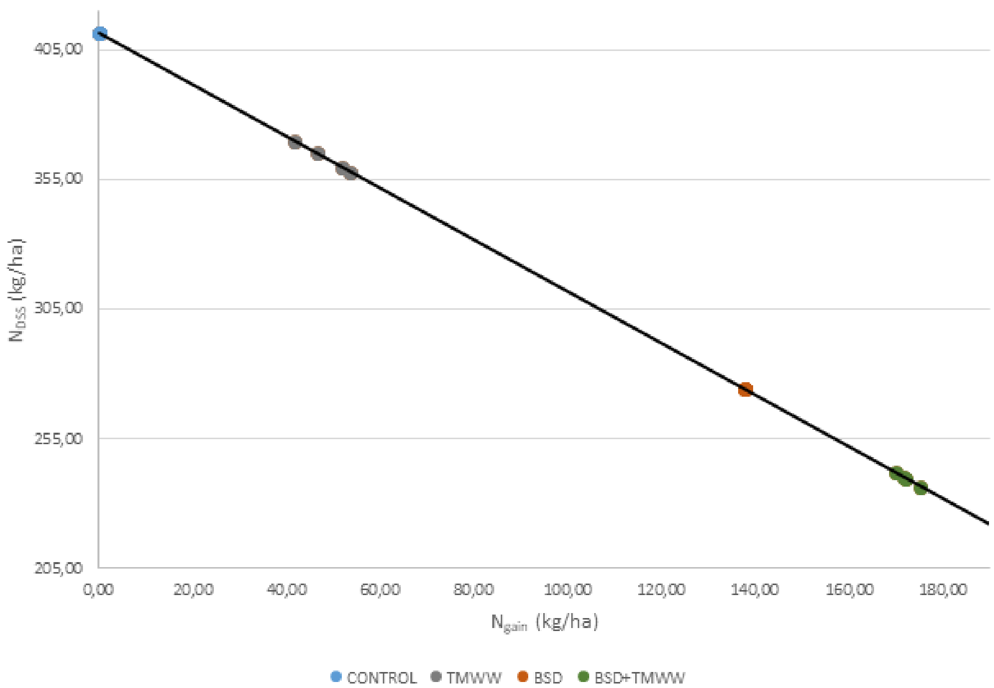

Figure 8
Effect of DSS-CP advised nitrogen gain (N_{gain}) on advised nitrogen levels (N_{dose}) for rational fertilization, under treated wastewater and biosolid, treatment

$$N_{DSS} = -1.00 \times N_{gain} + 411.85, \qquad R = 1.000, \qquad Sig. < 0.001$$

Soil Pollution. Since the present work is related to the reuse of TMWW and biosolids, it is expected that eventually, and after some years, heavy metals may accumulate in the agricultural soil at low or high rates, depending on the quality of the outflows reused. In such cases, the user can timely be informed about the process of soil pollution by the information that is provided by the pollution indices before and after the completion of the plant growth period, as shown in Table 4. It is the values of these indices which help the user to prevent the evolution of the accumulation of heavy metals in his agricultural soil. For example, the indices reported in this Table do not inform about pollution, as they are very low being determined before and after the completion of plant growth, respectively.

Table 3. *Evaluation of soil pollution level by means of pollution indices*

Soil	Value of pollution index EPI before irrigation with treated wastewater	Value of pollution index EPI after irrigation with treated wastewater	Evaluation of pollution level
Soil I	0.1229	0.1345	No pollution
Soil II	0.1771	0.2460	No pollution
Soil III	0.1698	0.2022	No pollution

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Rational fertilization of crops and determination of plant nutrient doses. One of the basic aim of the DSS-CP is via the exploitation of the wastewater and biosolids in agriculture the accomplishment of the rational fertilization of crops. This is made possible by using the soil pollution indices, as those of Table 3. The DSS-PC has been built in such a way that it can inform the user about the supply of possible additional complementary levels of plant nutrients to crops, apart from those supplied internally by the various nutrient sources of the soil, as already has been mentioned previously. In Table 4 are reported some examples of additionally supplied nutrients in three vegetables i.e., lettuce, peppers, and potatoes. These quantities are also expressed in the form of a respective inorganic fertilizer, as it will be explained in the following pages.

Table 4. *Advised plant nutrient doses application to* **lettuce, pepper and potato** *crops by the DSS-computer program under the reuse of TMWW and Biosolids*

Advised macro and micronutrient doses by the DSS-computer program to be applied in kg/ha	N	P_2O_5	K_2O	MgO	Fe	Zn	Mn	Cu	B
Soil I - Treated with TMWW and Biosolid Crop lettuce (Table 4)	70.25	0	0	0	0	0	0	0	0.42
Soil II - Treated with TMWW and Biosolid Crop pepper(greenhouse) (Table 5)	19.49	86.43	10.74	0	0	0	10.56	0	0
Soil III . Treated with TMWW and Biosolid Crop potatoes (Table 6)	88.95	0	0	0	0.31	0	9.38	1.59	0

Whenever the plant nutrients of the soil are not enough to cover the needs of the crops for maximum yield, the DSS-CP has been built to be capable of advising the user in relation to the optimum complementary nutrient levels of crop fertilization. The DSS-CP in cases of high fertility soils, do not advise application of fertilizers and this capacity is clearly seen in the following three soils cultivated with lettuce, peppers and potatoes as follows. Thus, in the case of the soil cultivated with lettuce, the DSS-CP advises the user to apply only N 70,25kg/ha in two doses of 65 and 195kg/ha of ammonium calcium nitrate, the latter being advised to be applied in 2-3 doses along with a small quantity of Borax. For all the rest of the nutrients the DSS-CP suggest zero application, as the soil is well supplied with all the rest macro, micronutrients (Table 5).

Table 5. *DSS rational crop fertilization advice for Soil I, treated with TMWW and Biosolid, crop lettuce*

Nutrient	Dose (kg/ha)	Fertilizer and guidelines for fertilizer
N	70.25	Dose: 1/4 65.05 kg/ha Ammonium Calcium Nitrate 27-0-0. Broadcasted and incorporated into the soil at transplanting - Dose: 3/4 195.14 kg/ha Ammonium Calcium Nitrate 27-0-0. Applied in 2-3 doses per 10 days interval at the onset of the plant growth.
P_2O_5	0	No fertilization required for the current year. Excessively high soil phosphorus. It is estimated that fertilization with phosphorus will be conducted after 3 years.
K_2O	0	No fertilization required for the current year.
MgO	0	No fertilization required for the current year. Excessively high soil magnesium. It is estimated that fertilization with magnesium will be conducted after 7 years.
Fe	0	No fertilization required for the current year.
Zn	0	No fertilization required for the current year.
Mn	0	No fertilization required for the current year. Excessively high soil manganese. It is estimated that fertilization with manganese will be conducted after 1 year.
Cu	0	No fertilization required for the current year. Excessively high soil copper. It is estimated that fertilization with copper will be conducted after 2 years.
B	0.42	Dose: 3.65 kg/ha Borax 11.5% or 2.0 5kg/ha Solubor 20.5%. Broadcasted mixed with other fertilizers.

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On the other hand, in the case of pepper it is advised the application of 19,49 kg/ha N, 86,43 P_2O_5 kg/ha, and 10,74 kg of K_2O/ha, as well as 10,56 kgMn, according to the guidelines mentioned in Table 6.

Table 6. *DSS rational crop fertilization advice for Soil II, treated with TMWW and Biosolid, crop pepper (greenhouse)*

Nutrient	Dose (kg/ha)	Fertilizer and guidelines for fertilizer
N	19.49	Dose: 1/4 18.05 kg/ha Ammonium Calcium Nitrate 27-0-0. Broadcasted and incorporated into the soil at transplanting – Dose: 3/454.14 kg/ha. Ammonium Calcium Nitrate 27-0-0. Surface applied beginning at the commencement of the flowering, and continued to the fruit set, in two applications per 10 days interval.
P_2O_5	86.43	432.15 kg/ha Simple Phosphate 0-20-0 or 187.89 kg/haSuper Phosphate 0-46-0 Broadcasted and incorporated into the soil at transplanting.
K_2O	10.74	21.48 kg/haPotassium Sulfate 0-0-50. Broadcasted and incorporated into the soil at transplanting.
MgO	0	No fertilization required for the current year. Excessively high soil magnesium. It is estimated that fertilization with magnesium will be conducted after 7 years.
Fe	0	No fertilization required for the current year.
Zn	0	No fertilization required for the current year.
Mn	10.56	33.00 kg/haManganese Sulfate 32% or 29.33 kg/haManganese Sulfate 36%. Broadcasted mixed with one of the above fertilizers at transplanting
Cu	0	No fertilization required for the current year. Excessively high soil copper. It is estimated that fertilization with copper will be conducted after 1 year.
B	0	No fertilization required for the current year.

Similarly, in the case of potatoes, as shown in Table 7 The user is advised to apply supplementary the following nutrients: 88,98 kg of N/ha, 0,31kg of Fe/ha, 9,38kg of Mn/ha, 1,59kg of Cu/ha. the method of application being given in the above Table according to the respective guidelines. Com parison of the advised quantities and kinds of nutrients between the above three tables (crops) shows that the advices given are based on the level of the available soil nutrient. Therefore, the soil of Table 5 (lettuce) was the most fertile, while the cases of the soil of Table 6, and Table 7, were less fertile as it was necessary to apply more nutrients supplementary. It is important to underline that the DSS-CP must be capable of recogni-

Table 7. *DSS rational crop fertilization advice for Soil III, treated with TMWW and Biosolid, crop potatoes*

Nutrient	Dose (kg/ha)	Fertilizer and guidelines for fertilizer
N	88.98	Dose 1/4 67.96 kg/ha Ammonium Nitrate 33.5-0-0. Broadcasted and incorporated into the soil at seed bed preparation - Dose 3/4 203.87 kg/ha Ammonium Nitrate 33.5-0-0. Surface applied beginning at the commencement of the flowering, and continued to the fruit set, in two applications per 10 days interval.
P_2O_5	0	No fertilization required for the current year.
K_2O	0	No fertilization required for the current year.
MgO	0	No fertilization required for the current year.
Fe	0.31	5.17 kg/ha Iron Chelate EDDHA Fe 6%. Applied by spray according to the manufacturer guidelines or broadcasted mixed with one of the above fertilizers.
Zn	0	No fertilization required for the current year.
Mn	9.38	29.31 kg/ha Manganese Sulfate 32% or 26.06 kg/haManganese Sulfate 36%.. Applied by spray or broadcasted mixed with one of the above fertilizers.
Cu	1.59	6.36 kg/haCopper Sulfate 25%. Applied by spray or broadcasted mixed with one of the above fertilizers
B	0	No fertilization required for the current year.

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zing these and many other cases and advise accordingly the application of the respective nutrient, making use of all the soil nutrient sources available.

Conclusions

Summarizing the above discussion referring to the credibility of the DSS-CP, the following are concluded: This tool proposed to be used for the exploitation of the wastewater and biosolids in agriculture, seems to be an effective means for the accomplishment of the so-called safe reuse of these effluents. Its credibility is strongly supported by means of many statistically documented relations between internal functions and external processes, which undoubtedly show that indeed the DSS-CP can be used effectively in wastewater and biosolid reuse in agriculture. It is an intelligent DSS-CP with many capacities that could help the users to make effective reuse of wastewater treatment plants by offering a series of services that may have economic, social environmental and health protection benefits.

Highlights: 1-The DSS-CP must be capable of providing optimum crop fertilization advises - 2-It must be versatile and effective tool in relation to wastewater and biosolid reuse - 3-It must be capable of foreseeing and preventing soil pollution with heavy metals and other toxic substances - 4-It also must protect the soil from heavy metal pollution, salt accumulation, and from acidification - 5- The DSS-CP may be easily accept adaptation of new technical possibilities for further improvement of its capacities

Statement of conflict of interest: we hereby declare that we do not have any conflict of interest.

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