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Application of the Plackett-Burman Design on Soil Fertility Determinants

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ABSTRACT

In the present review article, a soil from the region of Fez-Sefrou Morocco was screened for some physicochemical characteristics using the Plackett-Burman model in order to determine the most important factors that promote its fertility. Five independent variables were selected: pH, electrical conductivity, humidity, organic matter, and C/N ratio. These variables were evaluated by statistical analysis, based on their significance, the value of the coefficient of determination and the Pareto chart. The results suggest that humidity and C/N ratio have an influence with a high level of confidence, while the other three show no significant effect on the content of nutrients in the soil. The analysis of the R^2 variance value also showed that the models used for prediction were large and significant factors (p less than 0.05). Pareto chart plots for each response and its characteristics provided accurate data to select well-fitting variables for further optimization.

Keywords: screening, factors, variables, Plackett-Burman design, coefficient of determination, Pareto chart.

INTRODUCTION

In Morocco, the olive tree is the main cultivated fruit sector; it represents 65% of the tree cultivation and contributes to 5% of the national agricultural GDP. Covering an area of 784,000 hectares, the national farms total a production of about 1,500,000 tons of olives of which 40% are processed to produce 160,000 tons of olive oil. In terms of operations, 17,000 tons of olive oil and 64,000 tons of table olive are found in international markets. In addition, olive growing is an important source of employment, providing more than 51 million working days per year, the equivalent of 380,000 permanent jobs (MAPM, 2021). Nevertheless, the olive industry generates solid co-products called pomace and liquid called olives mill wastewater that it is important to valorize them to face the risks of potential pollution because of their acidity and their high organic load non-biodegradable (Majbar, 2019; Lahlou, 2019; Atemni et al., 2022; Mehdaoui et al., 2021). Indeed, the olive mill waste cake poses serious environmental problems, particularly in the basins by acidification of the environment, pollution of wadis and dams, disappearance of aquatic life as well as pollution of groundwater. They also have negative impacts on wastewater treatment plants by biological ways and on the soil bacterial microflora by its destruction, etc. (Essahalea et al., 2016).

Several ways of their ecological elimination have been experimented. Among them are composting (Majbar, 2019; Mehdaoui et al., 2021; Ben Abbou, 2014), vermicomposting (Sáez et al., 2021), collagen (Carrara et al., 2021) and soap production (Elkadri et al., 2019), antioxidant extraction (Muíño et al., 2017), and biogas extraction (Fernández-Prior et al., 2020).

The valorization of these wastes by anaerobic digestion for the production of a product having the characteristics of a good fertilizer requires the control of certain physicochemical parameters of which the principal ones are the pH, the electrical conductivity, the humidity, dry matter, organic matter, total organic carbon, Kjeldahl nitrogen, C/N ratio, and percentage of trace elements that significantly affect the content of fertilizing elements, especially nitrogen, phosphorus and potassium (N, P, K) (Elamin et al., 2019; Smita Tale et al., 2015; Agegnehua et al., 2016). Statistical design applications are currently being exploited to optimize the product components used in soil fertility (Lia et al., 2017; He et al., 2021; Anupam et al., 2015; Rose et al., 2018).

This review article aims at a valorization by co-composting of olive-growing waste to obtain a compost in conformity with the standards AFNOR; NFU 44-051 and NFU 44-551 relating respectively to the quality of an urban compost and its use as support of culture (AFNOR, 2015) which will be able to improve the quality of the ground by the presence of nitrogen, phosphorus and potassium; and consequently, to increase the agricultural output of the cultures. For this purpose, a Placket-Burman model was applied to evaluate the influence of certain variables on the content of these elements in the soil.

TOOL FOR SCREENING

Soil

Sandy soil of the Fés-Séfrou region.

Soil characterization methods

The soil was characterized by measuring pH, electrical conductivity (EC), humidity (%H), dry matter (%DM), Kjeldahl nitrogen (%KN), organic matter (%OM), total organic carbon (TOC) and C/N ratio according to AFNOR standards (AFNOR, 2004). The samples were collected using the random method by walking the field in a zigzag pattern.

Organic amendment

Compost with olive waste; elaborated on the basis of olive mill wastewater and olive pomace, organic household waste and poultry manures at a proportion of 25% each (Atemni et al., 2022).

Plackett-Burman model

The Plackett-Burman statistical design is very frequently used to detect the weight of factors on the response of a study. It is a two-factor design (i.e., -1 and +1) that locates the variables significant to the output by filtering "n" variables into "n+1" experiments (Karlapudi et al., 2018). Five factors were tested in the present investigation at both levels, based on the Plackett-Burman matrix (Table 1). The main effect was calculated essentially as a difference between the mean and the measures of each variable taken at a high level (+1) and a low level (-1). This design allowed variables to be filtered on the basis of a first-order model:

$$Y = + \beta_0 + \sum \beta_{i|} X_i \tag{1}$$

where: Y is the response (N, P, and K content), β_0 is the model intercept, and β_i is the variable estimates (Guindo et al., 2021). In this study, the variables were examined using the NEMRODW Software version 2007.

THE SCREENING RESPONSES

The Plackett-Burman model is an essential tool for screening the effects of process variables on performance; it can significantly reduce the number of repetitive experiments to be conducted in an additional optimization study, using response surface methodology (Ekpenyonga et al., 2017). The effect of variables on soil fertility assessed by N, P, K content was determined by running eight experiments given by the model (Table 2).

Table 1. Variables and levels used in the statistical design for screening soil components affecting the presence of the fertilizer elements N, P, K

Variable code	Variable name	Minimum value -1	Maximum value +1
A	pH	7	8.4
B	CE (μS/cm)	0.22	0.50
C	H (%)	6	13
D	MO (%)	4	7
E	C/N	1,4	12

Table 2. Effect of variables on soil fertility amended by the tested compost

N°Exp	A	B	C	D	E	% N	% P	% K
1	8.4	0.5	13	4	12	2.14	0.83	4.158
2	7	0.5	13	7	1,4	2.17	0.79	4.165
3	7	0.236	13	7	12	2.14	0.81	4.178
4	8.4	0.236	6.1	7	12	1.18	0.71	4.048
5	7	0.5	6.1	4	12	1.19	0.69	4.039
6	8.4	0.236	13	4	1,4	1.20	0.79	4.072
7	8.4	0.5	6.1	7	1,4	1.01	0.64	3.831
8	7	0.236	6.1	4	1,4	1.04	0.71	3.837

The regression equation was obtained using the Plackett-Burman design, which predicted the factors that influenced the three responses.

The equations were expressed by the determining the R^2 coefficient which is approximately 0.95 for N, P, K, and are represented as follows:

$$\text{Nitrogen (\%)} = 1.506 - 0.129A + \\ + 0.116B + 0.401C + 0.119D + 0.151E$$

$$\text{Phosphorus (\%)} = 0.746 - 0.004A - \\ - 0.009B + 0.059D + 0.014E$$

$$\text{Potassium (\%)} = 4.04 - 0.013A + \\ + 0.006B + 0.103C + 0.016D + 0.064E$$

The value of the R^2 coefficient between 0.90 and 0.95, confirms that the design is significant in predicting the effect of the variables on soil fertility detected by the contents of N, K and P, respectively.

Table 2 represents the effect of the studied parameters on soil fertility. Figures 1, 4 and 7 represent the Pareto charts of the factors influencing the presence of N, P and K elements, respectively.

Pareto diagram of nitrogen (N)

Of all the nutrients, nitrogen is the most difficult to control in fertilization. At the same time, it is the most important nutrient for crop growth and yield levels. Indeed, it is mainly nitrogen that determines the development of the plant and the roots that stimulate the optimal absorption of other nutrients from the soil.

However, soil nitrogen is mainly in organic form and must be mineralized by soil microorganisms in order to become available to plants during the growth phase. It is therefore difficult to know the amount and time of nitrogen mineralization in the soil; for this reason, several factors

Table 3. Coefficient estimations and statistics – nitrogen

Standard deviation of answer	0.28126944
R^2	0.920
R^2A	0.721
R^2 pred	N.D.
PRESS	2.5316
Number of degrees of freedom	2

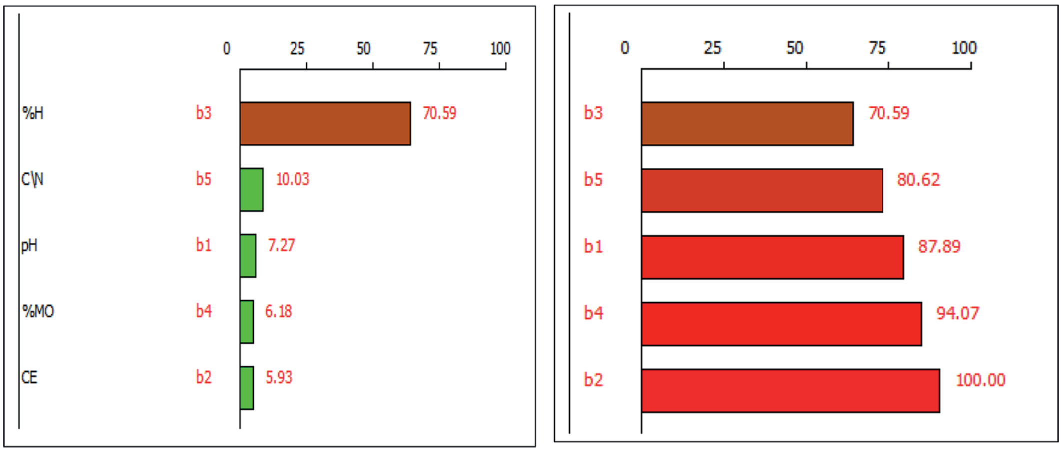

Figure 1. Pareto diagram of factors influencing the presence of nitrogen in the soil

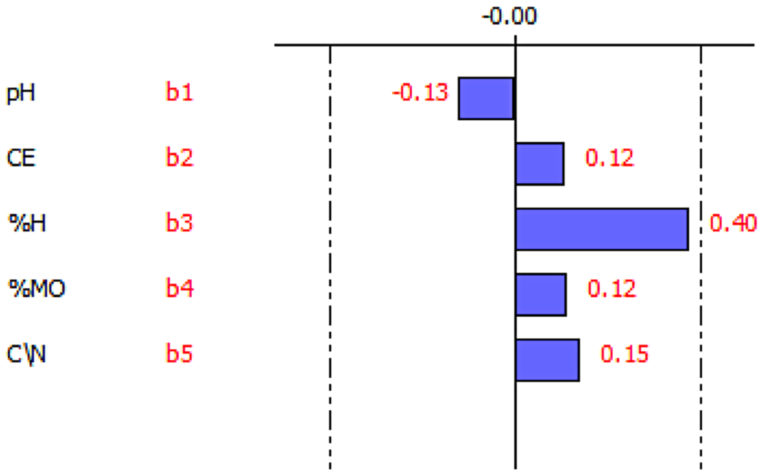

Figure 2. Graphical representation of factor coefficients for nitrogen

must be taken into consideration, such as crop rotation, organic or mineral fertilization methods, cultivation techniques, soil organic matter content and organic residues brought in, soil texture and structure, pH and soil-climate conditions (Kende et al., 2009). Thus, all these factors determine the growth and activities of soil microorganisms and consequently the amounts of N mineralized during the growing season (Geisseler et al., 2009). In addition, many biochemical processes regulate the balances between the different forms of N in the soil. In particular, mineralization and assimilation ensure the balance between mineral and organic forms of N, depending on the physical, chemical and biological parameters of the soil.

According to the Pareto diagram (Figure 1), two factors have a very important weight on the content of nitrogen in the soil: humidity with a percentage of 70.59% and the C/N ratio with 10.03%. Figure 2 and Table 3 confirm the same thing.

The result obtained corroborates that showing that the rates of nitrogen mineralization are a function of moisture, soil temperature and the activity of microorganisms in dry soil conditions (Guindo et al., 2021; Pandey et al., 2009). For example, well-drained sandy soils with high porosity lose their water content rapidly, either by infiltration or evaporation. In contrast, the soils containing clay or silt have smaller pores and can hold enough water, even in times of drought, to satisfy the needs of soil microorganisms (Marzi et al., 2020). Up to a certain limit, biological activities and nitrogen mineralization rates also increase along with soil temperature and humidity (Guindo et al., 2021; Pandey et al., 2009).

This is because the oxygen and CO_2 required by nitrifying microorganisms are contained within the soil pores; therefore, excessive humidity saturating the pores reduces soil aeration and nitrifying activity (Yang et al., 2019). Maximum mineralization would be reached at a humidity corresponding to 60–80% of the water holding capacity. In turn, the peak of denitrification would occur for a moisture content equal to the maximum water retention (Guindo et al., 2021).

As for the C/N ratio, an indicator of the degree of evolution of organic matter, its nature also influences the growth rate of microorganisms. It is known that easily mineralized organic matter increases and diversifies the soil microflora, and consequently the rates of OM decomposition and nitrogen mineralization.

On the other hand, for a good humification of the organic matter, it is very important that the carbon and nitrogen richness is between certain values, because the edaphic microfauna, microflora and microfungal, which act in the decomposition and mineralization of the organic matter, need carbon as a source of energy, and nitrogen as an intermediary in the synthesis of their proteins. If one of these elements is missing, mineralization slows down or even stops and, as a result, the plants do not have enough nutrients for their development and the soil may lose some of its structure, which will then make the soil less fertile (Bonanomi et al., 2019).

The conversion of organic nitrogen to inorganic nitrogen requires several chemical reactions catalyzed by different microbial enzymes (Figure 3).

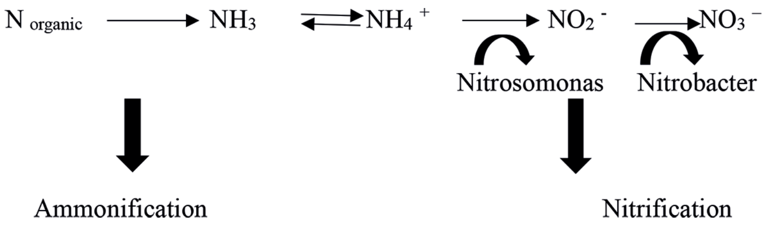

Figure 3. Dynamics of nitrogen mineralization in the soil

The ammonification process is driven mainly by peptidases and proteases that convert organic nitrogen into ammonia. It is followed by nitrification, involving the Nitrosomonas and Nitrobacter bacteria, which leads to the formation of nitrate, the final compound of mineralization. Mineralization is almost always accompanied by immobilization, but can also be accompanied by denitrification under wet conditions or in the presence of highly fermentable organic matter (Fujiia et al., 2020).

Denitrification is the release of N_2 or N_2O into the atmosphere from NO_2^-. Therefore, accumulated N contents are the result of net mineralization of M.O. which depends on the immobilization of N by soil biomass. The amount of N released is generally considered to be determined by the rate of N accumulation in the soil defined by the nitrification rate minus the denitrification rate (Yang et al., 2019).

Pareto diagram of phosphorus (P)

Phosphorus (P) has a role in a range of functions in plant metabolism and is one of the essential nutrients required for plant growth and development. It has structural functions in macromolecules, such as nucleic acids and energy transfer functions in metabolic pathways of biosynthesis and degradation. In contrast to nitrate and sulfate, phosphate is not reduced in plants but remains in its highest oxidized form.

Phosphorus is absorbed mainly during vegetative growth, most of which is transferred to fruits and seeds during the reproductive stages. Phosphorus-deficient plants show a delay in cell and leaf growth, respiration and photosynthesis, and often a dark green color (higher chlorophyll concentration) as well as a reddish coloration (increased anthocyanin production). It has been reported that the level of phosphorus supply during the reproductive stages regulates the partitioning of photosynthates between the source leaves and reproductive organs, this being essential for nitrogen fixing legumes (Mitran et al., 2018; FAO, 2020).

The Plackett-Burman model which is illustrated in Figures 4 and 5 and Table 4, has shown that humidity has an undeniable importance, which translates into a very high percentage reaching 90.64% in the mineralization of phosphorus in the soil. Indeed, the soils with low humidity can reduce microbial activity and consequently the rate of decomposition of organic matter and mineralization of organic phosphorus into inorganic phosphorus. Phosphorus moves from higher concentrations in the soil to lower concentrations in the plant roots by diffusion. As the soil becomes drier, diffusion decreases because the water film around the soil particles thins, making it more difficult to diffuse into the plant roots. This shows the important role of this factor in the mineralization of this element and therefore its content in the soil.

On the other hand, the physico-chemistry of phosphorus in most soils is quite complex, this being due to the existence of a series of instantaneous and simultaneous reactions such as dissolution, precipitation, retention and oxidation/reduction. Soluble phosphate compounds have very high reactivity, low solubility indices and low mobility. Mineralization and immobilization of organic phosphate compounds are the processes that are part of the phosphorus cycle in the soils containing significant amounts of organic matter (Filippelli, 2008).

Inorganic phosphorus is present mainly in the oxidized state, primarily as a complex with the metallic elements Ca, Fe, Al and with silicate minerals. Only a small part of soil P is directly or rapidly available to plants. It consists of soluble

Table 4. Coefficient estimations and statistics: phosphorus

Standard deviation of answer	0.027613403
R^2	0.952
R^2A	0.833
R^2 pred	0.237
PRESS	0.0244
Number of degrees of freedom	2

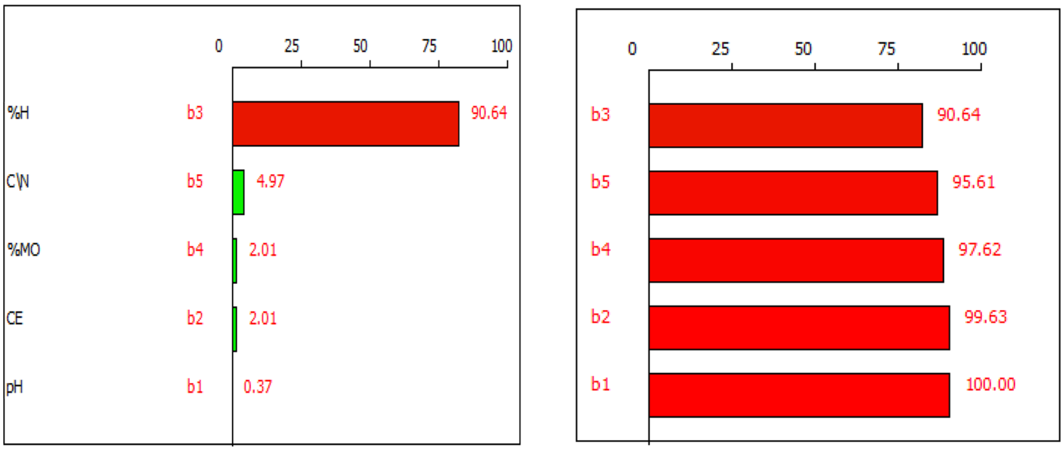

Figure 4. Pareto diagram of factors influencing the presence of phosphorus in the soil

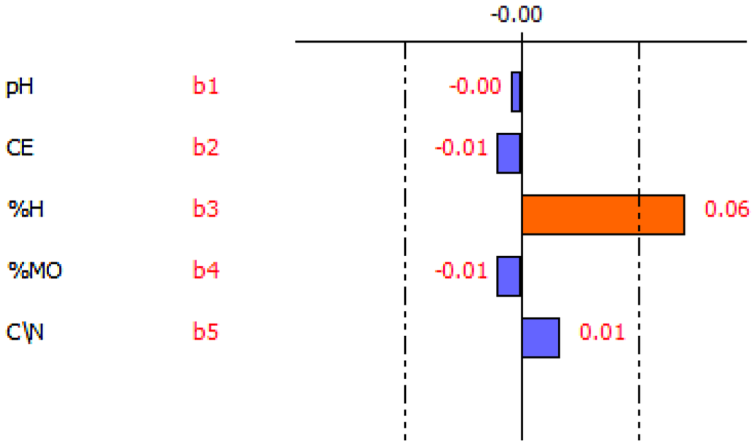

Figure 5. Graphical representation of factor coefficients for phosphorus

P, easily mineralized organic phosphorus (Po) and inorganic P weakly adsorbed on clay colloids (Duguet, 2005).

Phosphorus losses by leaching in organic soils are several times higher than those recorded in mineral soils. This can be attributed either to overfertilization or to the low proportion of Ca, Al and Fe compounds that are inorganic P binding agents in organic soils (Yan et al., 2013). The main enzymes responsible for the mineralization of soil organic phosphorus are intracellular (alkaline phosphatases) and extracellular (acid phosphatases) phosphatases, which are responsible for the final reaction leading to the release of phosphates from phosphate esters (Ghosha et al., 2018). Acid phosphatases present their optimum of activity at pH between 4 and 6. In contrast, alkaline phosphatases are most active at pH 9–11. In organic, acidic soils, acid phosphatases are therefore the most important for the mineralization of mineralizable organic phosphorus (Po) (Wanet et al., 2020). The activity of phosphatases is related to the organic carbon content of the soil, and affected by the moisture, pH and phosphate fertilization of the soil M.R. (Arenberg et al., 2019) and inhibited by copper (Wyszkowska et al., 2005; Yang et al., 2020).

Pareto diagram of Potassium (K)

Potassium plays two fundamental roles (Figure 6 and 7) – it is an enzymatic activator in metabolic processes such as the synthesis of proteins and sugars, and a physiological element that regulates the water content of cells and the absorption of cations. These different functions performed by potassium in crops are summarized by some authors as follows: the synthesis of soluble carbohydrates by photosynthesis; the balance of the amount of nitrogen in the plant to prevent intoxication of cells or depression of yields; the increase in resistance to drought by regulating stomatal openings and the decrease in leaf transpiration;

Table 5. Coefficient estimations and statistics – Potassium

Standard deviation of answer	0.081443999
R^2	0.901
R^2A	0.655
R^2 pred	N.D.
PRESS	0.21226
Number of degrees of freedom	2

the regulation of internal acidity (acid-base balance); the stimulation of tissue turgor by its action on membrane flexibility (Malvi et al., 2011).

Potassium is a major mineral element for plant development and growth. In cotton, it provides good yields and quality fiber (Gérardeaux, 2009). In cereals, potassium fertilization also increases yield and seed quality. In fact, potassium increases the resistance of plants to disease and promotes the synthesis and transport of assimilation products from the leaves to the seeds, thus increasing the weight of a thousand grains and thus the yield (Scanlana et al., 2015).

Following this study, the results show that the factors that have more weight on the content of potassium are: humidity with a percentage of 70.42% and the C/N ratio with 26.68%. The information in table 5 supports the same conclusion.

It is obvious that the entrainment of potassium at depth requires a certain amount of water percolating through a permeable soil. Thus, it is noted that the authors cited above use 60 cm as the reference depth in the ferritic soil zone, which is normally subject to high rainfall. In contrast, in drier climates with a long, well-defined dry season, the depth is only 15 cm. An example from South Africa shows the importance of this factor: a reduction of one third in rainfall leads in this case to a reduction in leaching of 30 to 40% (Christinaa et al., 2018).

If the soil is dry, there is a reduction in the passage of potassium into the plant's roots. As the

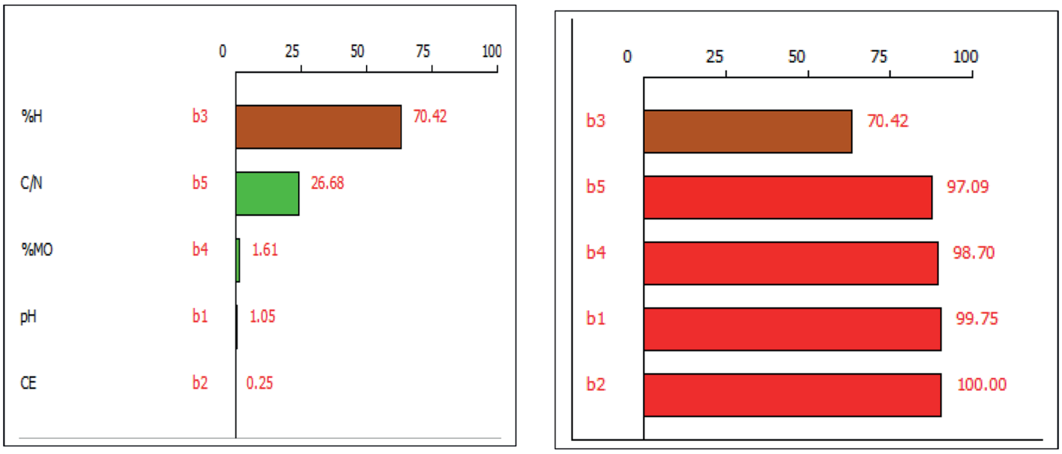

Figure 6. Pareto diagram of factors influencing the presence of Potassium in the soil

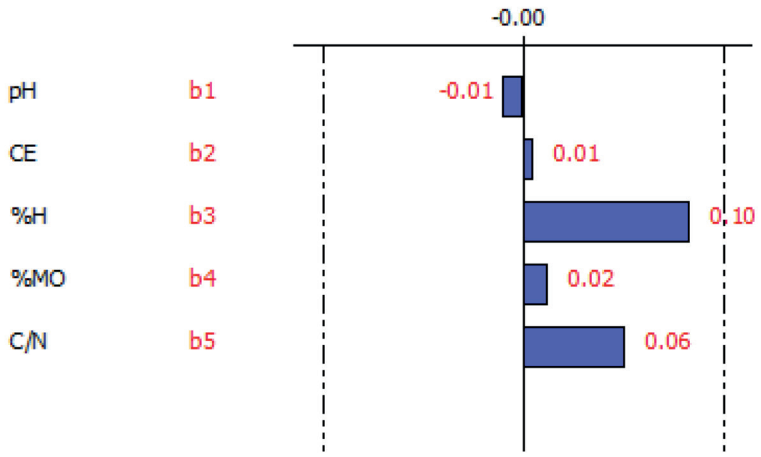

Figure 7. Graphical representation of the coefficients of the factors for Potassium

soil dries out, the clay minerals become dry and shrink, trapping potassium tightly between the mineral layers. The potassium, thus trapped, is no longer available to the plant roots. This potassium is released and can be taken up again by the plants if the soil moisture increases. Decreased potassium uptake during prolonged periods of soil dryness can result in low potassium concentrations in tissue samples or high potassium levels in the soil after harvest (MAAAR, 2021).

Moreover, the organic status of a soil, an essential parameter of its fertility, is currently most often assessed in a global and static way by the total organic carbon content, possibly completed by the carbon/nitrogen ratio. However, soil organic matter is a heterogeneous compartment, a mixture of carbonaceous compounds of diverse origins (plant, animal, microbial) and with equally diverse functions (stimulation of biological activity, mineral nutrition of the plant after mineralization, short- and long-term structural stability, etc.).

Moreover, in the soil, potassium is released during the growth phase of the plant from the solid phase of the soil. As for phosphorus, the potassium cycle is dependent on the physical and chemical characteristics of the soil. It is a fairly mobile element, but it can be adsorbed onto the cation exchange capacity CEC of soils. Potassium in the soil solution is retained by humus or clay; the potassium contained in minerals will only be released very slowly. The main pathways of loss of this nutrient are agricultural exports, leaching (more important in sandy soils, poor in organic matter and of low cation exchange capacity CEC) and finally runoff and erosion. On the other hand, the entry routes are mainly mineral fertilizers and organic inputs such as soil amendments that can be the source of important organic matter that results in a high C/N ratio that can guarantee a slow degradation of this OM and consequently obtain very stable humus.

CONCLUSIONS

Based on the literature analysis, this study identified the elements that have a strong support for soil fertility, especially the content of N, P and K. The factors, humidity and C/N ratio, were found to be considerable and have a very important weight to reach the maximum content of these elements. The results of reviewed papers revealed that the soil could produce good agricultural yields if it has a high percentage of moisture and a high C/N ratio.

While optimal rates of N, P and K can stimulate crop growth and productivity, excesses can lead to disease and insect infestations. This highlights the importance of establishing well-studied models to achieve good results in terms of soil quality and crop yield.

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REFERENCES

1. AFNOR. 2004. Evaluation de la qualité des sols, volume 1: méthodes d’analyses chimiques, volume 2 : méthodes d’analyses physiques et biologiques. (2004) E210-58.
2. AFNOR. 2015. Matières fertilisantes et support des cultures, Recueil sur CDROM Référence: 31845271 CD, ISBN 978-2-12-184271-4.
3. Agegnehua, G., Nelsona, P.N., Birda, M.I. 2016. Crop yield, plant nutrient uptake and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. Soil & Tillage Research, 160 1–13.
4. Anupam, K., Swaroop, V., Lal, P.S., Bist, V. 2015. Turning Leucaena leucocephala bark to biochar for soil application via statistical modelling and optimization technique. Ecological Engineering, 82, 26–39.
5. Arenberg, M.R., Arai, Y. 2019. Uncertainties in soil physicochemical factors controlling phosphorus mineralization and immobilization processes. Advances in Agronomy, 154, 153–200.
6. Atemni, I., Mehdaoui, I., Majbar, Z., Ainane, A., El Haji, M., Ben Abbou, M., Taleb, M., Rais, Z. 2022. Monitoring composting process of olive by -products and assessment of compost maturity.Environmental Engineering and Managment Journal, 8(21).
7. Ben Abbou, M. 2014. Impact des lixiviats de la décharge sauvage de la ville de Taza sur les ressources hydriques.
8. Bonanomi, G., Sarker, T. C., Zotti, M., Cesarano, G., Allevato, E., Mazzoleni, S. 2019. Predicting nitrogen mineralization from organic amendments: beyond C/N ratio by 13C-CPMAS NMR approach. Plant and Soil, 441(1), 129–146.

9. Carrara M., Kelly M.T., Roso F., Larroque M., Margout D. 2021. Potential of Olive Oil Mill Wastewater as a Source of Polyphenols for the Treatment of Skin Disorders: A Review. Journal of Agriculture and Food Chemistry, 69, 7268–7284.
10. Christina, M., Le Maire, G., Nouvellon, Y., Vezy, R., Bordon, B., Battie-Laclau, P., Laclau, J.P. 2018. Simulating the effects of different potassium and water supply regimes on soil water content and water table depth over a rotation of a tropical Eucalyptus grandis plantation. Forest Ecology and Management, 418, 4–14.
11. Duguet, F. 2005. Minéralisation de l'azote et du phosphore dans les sols organiques cultivés du sud-ouest du Québec.
12. Ekpenyong, M., Antai, S., Asitok, A., Ekpo, B. 2017. Response surface modeling and optimization of major medium variables for glycolipopeptide production. Biocatalysis and agricultural biotechnology, 10, 113–121.
13. Elamin, A.M. 2019. Energetic valorization of olive waste water (liquid waste) by methanic fermentation in north of Morocco. Environmental and Water Sciences, public Health and Territorial Intelligence Journal, 3(1), 53–59.
14. Elkadri, A., Elfkih, S., Sahnoun, H., Albouchi, L., Abichou, M. 2019. Etude strategique et économique de la gestion des margines : ces des projets de décharge des margines au gouvernorat de sousse (Tunisie). Revue Ezzaitouna.
15. Essahalea, A., Karrouch, L. 2015. Contribution a` l'étude de l'impact des huileries de la province d'El Hajeb sur l'environnement. Archives des Maladies Professionnelles et de l'Environnement 76:355-365 1775-8785X.
16. FAO. 2020. Organisation des Nations Unies pour l'alimentation et l'agriculture, http://www.fao.org/news/archive/newsbydate/2020/fr/
17. Fernández-Prior, Á., Trujillo-Reyes, Á., Serrano, A., Rodríguez-Gutiérrez, G., Reinhard, C., Fermoso, F.G. 2020. Biogas Potential of the Side Streams Obtained in a Novel Phenolic Extraction System from Olive Mill Solid Waste. Molecules, 25, 5438.
18. Filippelli, G.M. 2008. The global phosphorus cycle: past, present, and future. Elements, 4(2), 89–95.
19. Fujii, K., Yamada, T., Hayakawa, C., Nakanishi, A., Funakawa, S. 2020. Decoupling of protein depolymerization and ammonification in nitrogen mineralization of acidic forest soils. Applied Soil Ecology, 153, 103572.
20. Geisseler, D., Horwath, W.R., Doane, T.A. 2009. Significance of organic nitrogen uptake from plant residues by soil microorganisms as affected by carbon and nitrogen availability. Soil Biology and Biochemistry, 41(6), 1281–1288.
21. Gérardeaux, E. 2009. Adjustment of phenology, growth and dry matter production of cotton (Gossypium Hirsutum L.) facing potassium deficiency.
22. Ghosh, S., Goswami, A.J., Ghosh, G.K., Pramanik, P. 2018. Quantifying the relative role of phytase and phosphatase enzymes in phosphorus mineralization during vermicomposting of fibrous tea factory waste. Ecological engineering, 116, 97–103.
23. Guindo, S.S., Sacko, S., Goita, O., Diawara, B., Dabo, H., Dembele, C., Plea, M. 2021. Effet du taux d'humidité sur la minéralisation de différentes sources de matières organiques dans les sols sous cultures riz et blé au Mali. Symposium malien sur les sciences appliquées (MSAS).
24. He, J., Wang, J., He, D., Dong, J., Wang, Y. 2011. The design and implementation of an integrated optimal fertilization decision support system. Mathematical and Computer Modelling, 54, 1167–1174.
25. Karlapudi, A.P., Krupanidhi, S., Reddy, R., Indira, M., Md, N.B., Venkateswarulu, T.C. 2018. Plackett-Burman design for screening of process components and their effects on production of lactase by newly isolated Bacillus sp. VUVD101 strain from Dairy effluent. Beni-Suef University journal of basic and applied sciences, 7(4), 543–546.
26. Kende, S. 2010. Minéralisation de l'azote dans deux sols amendés avec deux composts enrichis d'un antibiotique.
27. Lahlou, K. 2019 Valorisation des boues dans la filière de compostage : élaboration et application.
28. Lia, R., Taoa, R., Lingb, N., Chua, G. 2017.Chemical, organic and bio-fertilizer management practices effect on soil physicochemical property and antagonistic bacteria abundance of a cotton field: Implications for soil biological quality. Soil & Tillage Research, 167, 30–38.
29. MAAAR. 2021. Ministére de l'Agriculture, de l'Alimentation et des Affaires Rurales. http://www.omafra.gov.on.ca/french/crops/hort/news/hortmatt/2016/11hrt16a2.htm consulted at 14\10\2021.
30. Majbar, Z. 2019. Traitement des margines par un procédé couplant l'électrocoagulation et l'adsorption sur des charbons actifs de la sciure de bois d'eucalyptus et leur valorisation par la filière de compostage des déchets vinicoles.
31. Malvi, U.R. 2011. Interaction of micronutrients with major nutrients with special reference to potassium. Karnataka Journal of Agricultural Sciences, 24(1).
32. MAPM. 2021. Ministère de l'Agriculture et de la Pèche Maritime. - L'agriculture marocaine en chiffres. https://www.agriculture.gov.ma/fr/filiere/olivier.
33. Marzi, M., Shahbazi, K., Kharazi, N., Rezaei, M. 2020. The influence of organic amendment source

on carbon and nitrogen mineralization in different soils. Journal of Soil Science and Plant Nutrition, 20(1), 177–191.

34. Mehdaoui, I., Majbar, Z., Atemni, I., Jennan, S., Ainane, T., Gaga, Y., Taleb, M., Rais, Z., Chetouani, A. 2021. What effects does an organic amendment to olive waste have on the soil and crop yield? Moroccan Journal of Chemistry, 9(4), 9–4.
35. Mitran, T., Meena, R.S., Lal, R., Layek, J., Kumar, S., Datta, R. 2018. Role of soil phosphorus on legume production. In Legumes for soil health and sustainable management, 487–510.
36. Muíño, I., Díaz, M.T., Apeleo, E., Pérez Santaescolástica, C., Rivas Cañedo, A., Pérez, C., Cañeque, V., Lauzurica, S., De la fuente, J. 2017. Valorisation of an extract from olive oil waste as a natural antioxidant for reducing meat waste resulting from oxidative processes. Journal of Cleaner production, 924–932.
37. Pandey, C.B., Srivastava, R.C., Singh, R.K. 2009. Soil nitrogen mineralization and microbial biomass relation, and nitrogen conservation in humid-tropics. Soil Science Society of America Journal, 73(4), 1142–1149.
38. Rose, S., Nickolas, S., Sangeetha, S. 2018. Machine Learning and Statistical Approaches used in Estimating Parameters that Affect the Soil Fertility Status: A Survey. In 2018 Second International Conference on Green Computing and Internet of Things (ICGCIoT). IEEE, 381–385.
39. Sáez, J.A., Pérez-Murcia, M.D., Vico, A., Martínez-Gallardo, M.R., Andreu-Rodríguez, F.J., López, M.J., Bustamante, M.A., Sanchez-Hernandez, J.C., Moreno, J., Moral R. 2021. Olive mill wastewater-evaporation ponds long term stored: Integrated assessment of in situ bioremediation strategies based on composting and vermicomposting. Journal of Hazardous Materials, 402, 123481.
40. Scanlan, C.A., Bell, R.W., Brennan, R.F. 2015. Simulating wheat growth response to potassium availability under field conditions in sandy soils. II. Effect of subsurface potassium on grain yield response to potassium fertiliser. Field Crops Research, 178, 125–134.
41. Seyedghasemi, S.M., Rezvani Moghaddam, P., Esfahani, M. 2021. Optimization of biochar and nitrogen fertilizer in rice cultivation. Journal of Plant Nutrition, 44(12), 1705–1718.
42. Smita Tale K., Ingole S. 2015. A Review on Role of Physico-Chemical Properties in Soil Quality. Chemical Science Review and Letters, 4(13), 57–66.
43. Wan, W., Hao, X., Xing, Y., Liu, S., Zhang, X., Li, X., Huang, Q. 2021. Spatial differences in soil microbial diversity caused by pH-driven organic phosphorus mineralization. Land Degradation & Development, 32(2), 766–776.
44. Wyszkowska, J., Kucharski, J., Lajszner, W. 2005. Enzymatic Activities in Different Soils Contaminated with Copper. Polish Journal of Environmental Studies, 14(5), 659–664.
45. Yan, Z., Liu, P., Li, Y., Ma, L., Alva, A., Dou, Z., Zhang, F. 2013. Phosphorus in China's intensive vegetable production systems: overfertilization, soil enrichment, and environmental implications. Journal of Environmental Quality, 42(4), 982–989.
46. Yang, R., Xia, X., Wang, J., Zhu, L., Wang, J., Ahmad, Z., Chen, Y. 2020. Dose and time-dependent response of single and combined artificial contamination of sulfamethazine and copper on soil enzymatic activities. Chemosphere, 250, 126161.
47. Yang, Y., Zhang, H., Shan, Y., Wang, J., Qian, X., Meng, T., Cai, Z. 2019. Response of denitrification in paddy soils with different nitrification rates to soil moisture and glucose addition. Science of the Total Environment, 651, 2097–2104.