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Evaluation of the plant pattern of intercropping in chemical soil elements using the nonlinear response surface model

Mehdi Dahmardeh[1*], Behrooz Keshtegar[2], Mahdieh Rajaei[1], and Issa Khammari[1]

[1]*Faculty of Agriculture, University of Zabol, Iran*
[2]*Faculty of Engineering, University of Zabol, Iran*
[*]*E-mail:* dahmard@gmail.com

Abstract

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The suitable culture to improve soil fertilities based on chemical properties is one of the most important decisions to implement a suitable culture for the stability of income of farmers in arid regions. The effects of vermicompost and the different patterns of intercropping, including corn, peanut and borage are evaluated on optimum conditions of chemical soil elements such as nitrogen, phosphorus, sodium and carbon. The experimental data are extracted form a dry climatic region in southeast Iran, using three levels of vermicompost (0, 2.5, and 5 t/ha) and nine levels for the intercropping (including pure culture of corn, peanut, and borage in the following proportions: replacement and additive design) using split plot design, which is based on RCBD with three replications during 2015-2016. The Nonlinear Modeling-based Response Surface Method is used to predict the chemical soil elements based on vermicompost and intercropping. The effects of the different culture patterns are investigated to illustrate the sensitivity of soil fertilization. The best pattern to improve the soil's elements is obtained by increasing the proportion of the peanut in intercropping, introducing five t/ha of vermicompost, and establishing an intercropping of 80% peanut + 50% corn + 50% borage for increasing the soil nutrients.

Keywords: organic carbon; intercropping; chemical soil elements; vermicompost; nonlinear modeling

Introduction

One of the most important decisions facing farmers involves determining the optimum culture pattern. Using this pattern, most of the proceeds of a certain number of institutions (or at least the cost to generate a certain combination of products) can be determined. Production and efficiency of crop yields are always influenced by numerous conditions and factors that are not under the control of the farmer; therefore, these two indicators fluctuate with changing conditions and the effects of the stability of farmers' incomes (Di Falco et al., 2007). From the perspective of sustainable agriculture, soil not only has a physical and chemical context but it is also a living body, managing its live inventory, its biodiversity, and health and its function can be maintained and increased. Consequently, to achieve a sustainable agricultural system, the use of inputs, which, besides meeting the needs of plants, improves the ecological aspects of the system and reduces environmental hazards, seems necessary (Kızılkaya, 2008). The results of certain studies show that organic fertilizers, such as vermicompost, are sustainable solutions to conserve and improve soil fertility, especially in arid and semi-arid areas with low input organic material, vermicompost contains significant amounts absorbable nutrients such as phosphorus, potassium, calcium, and magnesium (Atiyeh et al., 2000a, 2000b). Application of vermicompost not only reduces the need to use chemical fertilizers on agricultural land but also increases plant resistance against biotic and abiotic stresses (Paul and Metzger, 2005; Theunissen et al., 2010). The intercropped legume/cereal systems reduce interspecific competition by enhancing the compel mentality/facilitation processes, thereby improving the exploitation of resources, which is reflected in the increase in plant production corresponding to a greater efficiency of agro-ecosystem as a whole (Duchene et al., 2017). Continuous bean/maize and wheat/maize intercropping for the longer term provided nutrient acquisition compared to the sole crop or rotations, and continuous intercropping increased productivity, the soil chemical properties and the enzyme activities over a long period (Wang et al., 2015). In the mixed system of corn and peanut plants, the amounts of organic carbon, nitrogen, sodium, potassium, calcium, and magnesium of the soil were affected by the sowing system after harvest; the increase and the decrease of each element varied according to the percentage of the aforementioned elements in the plants and the different morphological structures between the two plants (Rajaii and Dahmardeh, 2014). The intercropping system increased the soil microbial activity and the complementary use of nitrogen-enhanced efficiency of the soil resources, especially in the non-N fixing crop in comparison with monoculture (Bedoussac et al., 2014). The study of intercropped wheat and chickpea in soil, amended with iron phosphate or phytate, confirmed that intercropping can increase the combined yield of the two species and the combination of growth and P uptake of both of these crops was improved by root contact (Wang et al., 2007). The culture of roselle (*Hibiscus sabdarifa*) and mung bean (*Vigna radiata*) was modeled based on the different percentages of the mixture. The results showed that increasing the cultivation area of roselle had a negative effect on soil properties, whereas increasing the cultivation area of mung bean, in comparison to hibiscus, provided a positive effect on the amount of nitrogen and carbon to which the soil temperature showed affective correlation with the culture type in comparison to the tillage on soil properties; increasing the cultivation area of mung bean had a positive effect on soil carbon and nitrogen (Dahmardeh and Hodiani, 2016). The study of intercropping maize with rapeseed, pea, and wheat in arid irrigation areas demonstrated enhanced water-use efficiency, land equivalent ratio, energy yield. In addition to these positive attributes, it also decreased C emissions and thus maize-based intercropping systems were the most effective and sustainable production systems for arid irrigation areas (Chai et al., 2014). Rice/peanut intercropping resulted in high rice grain yield and this was mainly attributed to the improvement in N (nitrogen) nutrition supplied by the intercropped peanut. The N transferred from the peanut plant made a significant contribution to the N nutrition of rice, especially in low-N soil (Chu et al., 2004). Organic fertilizers play a significant role in sustainable agriculture and their usage constitutes an important factor for plant diversity. Intercropping with respect to two plants (Rajaii and Dahmardeh, 2014; Dahmardeh and Hodiani, 2016) showed suitable plant patterns to improve the chemical properties of the soil element. The variety of the percentages of the mixture plants can be affected through the fertilization of the soil during intercropping in the arid area. The different intercropping patterns and the vermicompost levels can be used for novel mixture patterns to improve the chemical properties of soil in the intercropping of desert regions. The effects of intercropping patterns and vermicompost levels can be calibrated based on nonlinear mathematical models to search the optimum conditions of the mixed agriculture system. The Response Surface Method (RSM) is a useful mathematical modeling tool for the prediction of events based on the second-order polynomial function (Liu and Moses, 1994; Hou et al., 2007). The RSM might not provide accurate results for some cases of high-nonlinear predictions based on the second-order polynomial function (Keshtegar et al., 2016). Consequently, the accurate prediction-based nonlinear model is a more important key to search for a suitably mixed pattern to improve the fertilization of soil in intercropping.

In the present study, the chemical properties of soil elements in the nine intercropping patterns and the three levels of vermicompost are examined for a region with hot and dry climatic conditions in southeast Iran. The climate of this area is very arid, which includes dry weather with an absolute maximum temperature 46°C and a minimum temperature -5.4°C, over 3,200 sunshine hours, 120-day winds (from the middle of May to the middle of September), and 5.000 mm evaporations in the summer. The experiments of mixed patterns are calibrated using a novel nonlinear form-based response surface method that is based on intercropping patterns and vermicompost levels on chemical soil elements, including nitrogen, phosphorus, sodium, and carbon in the soil. The nonlinear modeling has been developed based on two calibrated steps with the exponential function in the first stage and high-nonlinear polynomial functions in the second stage. The two proposed regressed nonlinear modeling methods, using the high-order response surface method (RSM), can produce an accurate correlation between the independent variables (i.e., vermicompost and intercropping patterns) and the soil elements. Finally, a sensitivity analysis is presented to illustrate the effects of the input variables on the chemical properties of soil. According to these results, the highest nutrients' ratio was observed in the planting proportion of 80% peanut + 50% corn + 50% borage. In the process of modeling, the increased peanut proportion in the pattern was more effective than corn and borage in the amount of nutrients soil.

Material and Methods

To evaluate the effect of the intercropping patterns and the applications of organic fertilizers on the changes of soil elements using nonlinear modeling, the split-plot test, based on randomized complete block design with three replications, was conducted between 2015 and 2016 at the Institute of Zabol University, which is located in Zahak. The location of this study was 61°41′ East and a latitude of 30° 54′, at an altitude of 481 m above sea level; a somatic view of this location is shown in Fig. 1. The experimental station in Zahak has a very arid and hot climate with a maximum temperature 46°C and a minimum temperature of -5.4°C in year; difference in air temperature may occur at temperatures higher than 50°C owing to dry weather, which is the shortest in January and the longest in June, with over 3,200 sunshine hours in a year. The number of drought months with no rainfall is seven and scarce precipitation is observed (about 50 mm annually) in the region. In summers, the annual potential of evapotranspiration is more than 5,000 mm with 120-day winds that start in the middle of May and continue till the middle of September, with wind speeds of more than 100 km/h.

The studied factors comprised various proportions of vermicompost as a major factor in three levels (including 0, 2.5, and 5 tons per hectare), different patterns of intercrop-

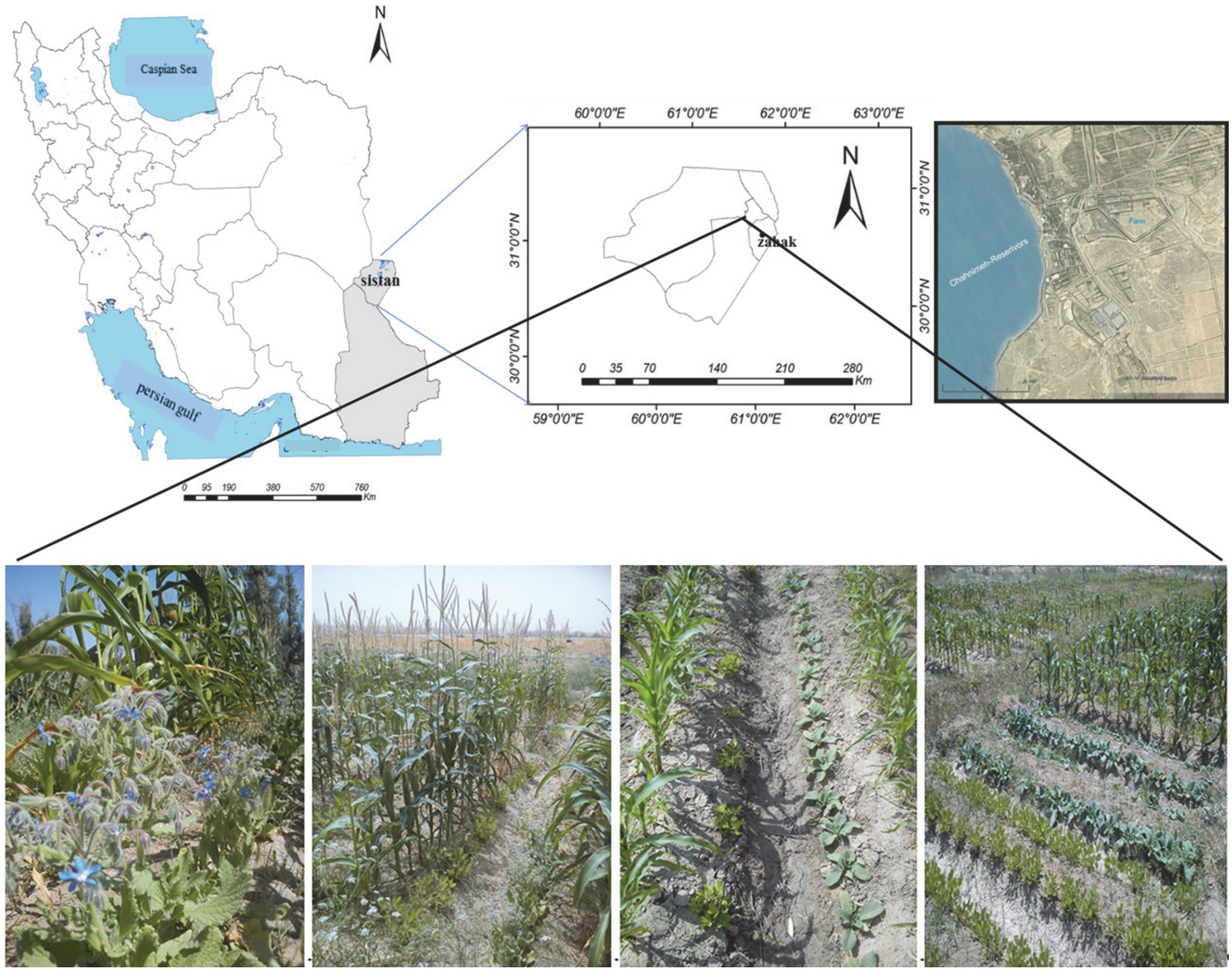

Fig. 1. Location of the study area

ping as a sub factor in nine levels including the monocultures of corn, peanut, and borage, 50% corn + 25% peanut + 25% borage, 100% corn + 50% peanut + 50% borage, 40% corn + 30% peanut + 30% borage, 100% corn + 75% peanut + 25% borage, 60% corn + 20% peanut + 20% borage, and 100% corn + 25% peanut + 75% borage. Pure cultures of the three plants in the desired density (i.e., the distance between the rows of the three plants was 50 cm; the distances between the rows of corn, peanut, and borage were 20 cm, 15 cm, and 20 cm, respectively); the final density of mixed treatment with regard to the plans studying the increase and the replacement in the three plants (in terms of row-spacing with respect to the two methods of intercropping) were different. Before carrying out field experiments, sampling was performed at a depth of zero to 30 cm in the test site. The soil chemical properties of the test site have been shown in Table 1.

Table 1
Soil testing in main samples of soil

PH	EC ds/m	Phosphorus ppm	Nitrogen %	Sodium m.e/Lit	Organic carbon %
8.12	1.8	8	0.029	12.5	0.31

After land preparation, the planting of the three plants was conducted in plots with dimensions of 9 m^2 in late March 2014 and 2015. The cultivars that were used in this experiment were single-cross 260 corn (*Zea mays*) with a growth period of 105-115 days, peanut (*Arachis hypogaea*) varieties with a growth period of 180-210 days, and borage (*Borago officinalis*) with a growth period of 100-110 days. The single-cross hybrid 260 corn had an average yield of 10-11 tons of grain per hectare and the peanut plant had unlimited plant growth and plant-growth type. Vermicompost was incorporated into strips while planting in rows. Soil sampling was conducted after harvesting three plants from the roots of the plants and the soil elements; this included sampling of organic carbon by the Walkley-Black method (Walkley and Black, 1934), nitrogen using the Kjeldahl method (Kjeldahl, 1883), phosphorus in the extracts was obtained from Olsen's method (Olsen et al., 1954) using a spectrophotometer, and sodium dissolved in saturated extracts was sampled with the flame-photometry method using the flame photometer; these samples were thereafter measured. On the basis of the intercropping patterns and the three levels of vermicompost, the average (Mean), maximum (Max), minimum (Min), standard deviations, and the coefficient of variations of experiments for the soil elements were listed in Table 2.

Nonlinear modeling using Response Surface Method

The RSM is a useful modeling approach to predict the chemical, physical, engineering, and environmental problems (Liu and Moses, 1994; Hou et al., 2007; Keshtegar et al., 2016). Generally, the second-order response surface function with cross terms is implemented for calibrating the real complex problems. The chemical soil elements in intercropping with various vermicomposts can be predicted based on the following polynomial response surface function:

$$Y(SE) = b_0 + \sum_{i=1}^{n} b_i X_i + \sum_{i=1}^{n} \sum_{j=i}^{n} b_j X_i X_j \qquad (1)$$

in which, n is the number of input variables, which is two in this paper – intercropping patterns (IC) and vermicompost levels (VC). The unknown coefficients of the polynomial function with cross terms are named b_0, b_1, and b_{ij}. The mathematical function mentioned above may produce inaccurate results for complex problems with highly nonlinear characteristics. Therefore, the RSM has been improved to enhance the accuracy of prediction based on two regressed steps in this current paper. This regression can be provided with a greater potential to fit the model in these experiments. Nonlinear regressions are applied based on the exponential function in the first calibrated step for each variable. The calibrated data points from the first step are transferred based on the hyperbolic tangent sigmoid transfer function and then the transferred data are calibrated based on the polynomial-response surface functions with the high-order form. The structure of the proposed nonlinear mathematical model is shown in Fig. 2.

Table 2
Statistical properties of the input variables including vermicompost and intercropping in soil elements

Nutrients of soil	Mean	Value		Standard deviation	Coefficient of variation (%)
		Max	Min		
Carbon (%)	0.373	0.450	0. 294	0.037	9.8
Phosphorus (ppm)	6.061	8.851	4.167	1.128	18.6
Sodium (m.e/lit)	13.982	34.450	7.433	2.685	19.2
Nitrogen (%)	0.032	0.043	0.027	0.004	11.7

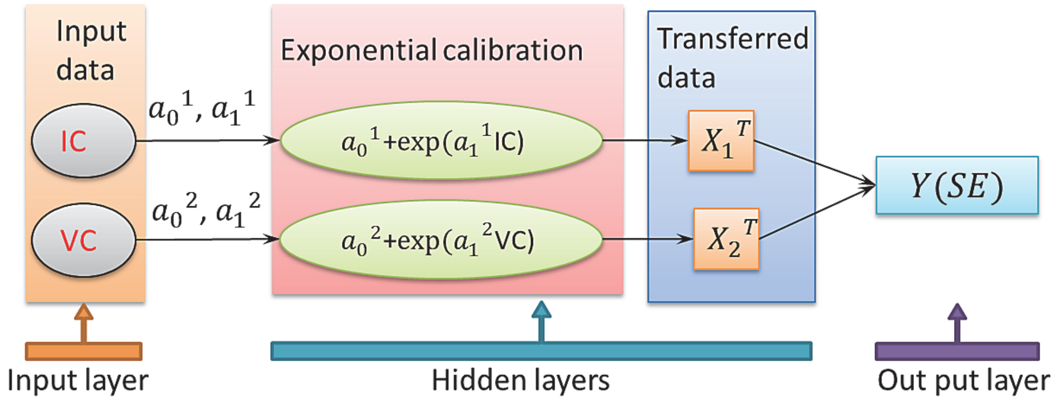

Fig. 2. The structure of the proposed high-order RSM

The modeling approach based on the framework in Fig. 2 can be defined by the following two-step calibrations:

Step 1: Exponential calibration

Each soil element is calibrated based on an input variable including IC or VC by the following relations:

$$Y_1(SE) = a_0^1 + a_1^1\exp(IC) \tag{2a}$$

$$Y_2(SE) = a_0^2 + a_1^2\exp(VC) \tag{2b}$$

where a_0^1 and a_1^1 are the unknown coefficients for the exponential function, which should be calibrated for the input of the first variable, i.e., IC; a_0^2 and a_1^2 are the unknown coefficients for the second variable, i.e., VC. Based on the above calibration, two predicted data, Y_1 and Y_2, are obtained, which are regressed based on the basic input data and the chemical soil elements. These two calibrated data points are used for the input data in the RSM using nonlinear forms as a third-order polynomial function in the second regressed step.

Step 2: Polynomial calibration

This step in the proposed RSM involves two stages, transferring the input data and calibrating the transfer data; thus we have transfer the input data from Step 1 based on the hyperbolic tangent sigmoid function as

$$X_t^T = \frac{\tanh(Y_i)}{\tanh(\max(Y_i))} \quad i=1,2 \tag{3}$$

where Y_i is the calibrated data from the exponential regression and $\max(Y_i)$ is the maximum calibrated point from the first stage. X_t^T is obtained based on exponential regression and a nonlinear transfer that can be defined based on a nonlinear map uisng the exponential forms with the hyperbolic tangent function. The third-order polynomial function is regressed based on the following relations:

$$Y(SE) = b_0 + b_1X_1^T + b_2X_2^T + b_3X_1^{T2} + b_4X_2^{T2} + b_5X_1^TX_2^T + \\ + b_5X_1{}^{T3} + b_6X_2{}^{T3} + b_7X_1^TX_2^{T2} + b_8X_1^{T2}X_2^T \tag{4}$$

The nonlinear regression method is applied with two-step calibrations in the modeling approach. The above nonlinear high-order polynomial function can be provided a flexibility for calibrating data in comparison to the original RSM in Eq. (1). This nonlinear model is calibrated based on the sum squared estimator, which is defined by Keshtegar et al., (2016).

Fig. 3 illustrates the scatterplot of the predicted and observed data of soil elements in the train (35 data) and the test (10 data). As observed, the proposed method can be more accurately predicted in the soil elements. All the linear correlations between the predicted and the observed data points are obtained to be greater than 0.91, such that phosphorus and carbon are predicted as the best and the worst correlations, respectively, among the other chemical proprieties of the soil. The train data points are predicted as being very close to the observed data in comparison to the testing data point, but the accuracy of the testing data point is acceptable (containing relative errors of less than 5%). Thus, through this nonlinear modeling approach-based RSM, the chemical properties of the soil can be predicted in intercropping for three plants.

Results

The sensitivity using the marginal effects of the percentage of peanut, borage, and corn, based on three levels of vermicompost, i.e., 0, 2.5, and 5 ton/ha, has been investigated on the chemical soil properties such that the marginal effects

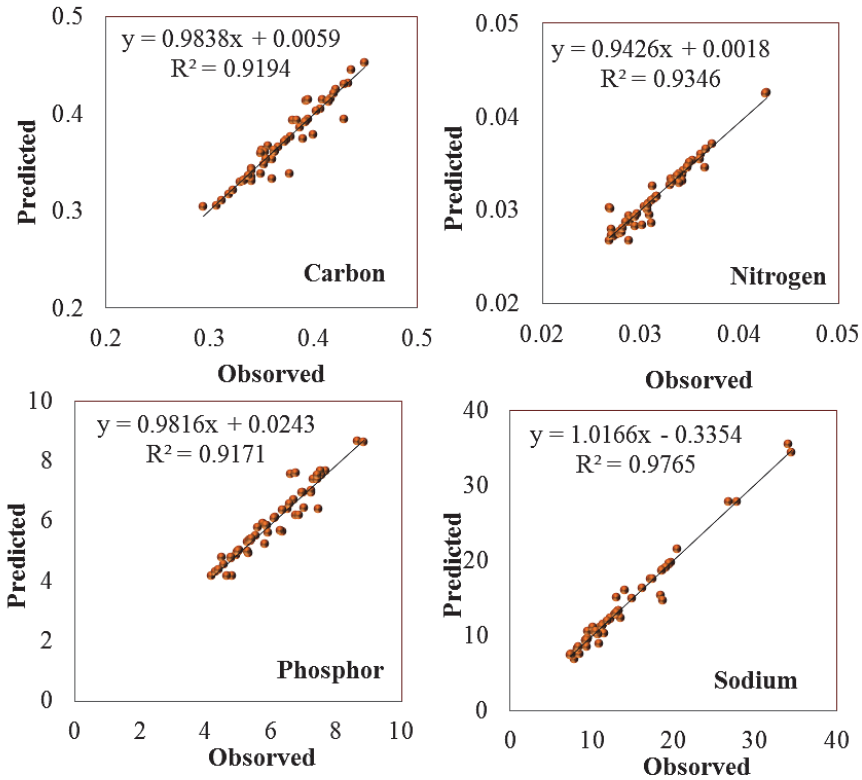

Fig. 3. Scatterplot of observed soil elements and predicted using highly nonlinear response surface method

based on the finite difference approach can be obtained as follows:

$$ME(x) = Y(SE + A) - Y(SE) \tag{5}$$

where $ME(x)$ is the marginal effect of the vermicompost on soil elements for peanut, borage, and corn. The different considered levels of vermicompost are 0, 2.5, and 5 ton/ha in this study. The increasing rate, based on the parameter A, is considered to demonstrate the effect of the vermicompost on the soil elements that include nitrogen, phosphorus, carbon, and sodium as follows:

Nitrogen

The effects of different vermicompost levels in intercropping for the three levels of vermicompost on soil nitrogen are shown in Fig. 4. From Fig. 4, in all the cropping patterns, it is evident that the amount of nitrogen in the soil is increased by increasing vermicompost. In this regard, the use of vermicompost, as an organic fertilizer, is used to increase soil nitrogen as an essential element of the soil. The best treatment of the soil is carried out across all planting patterns through the application of five tons of vermicompost per hectare.

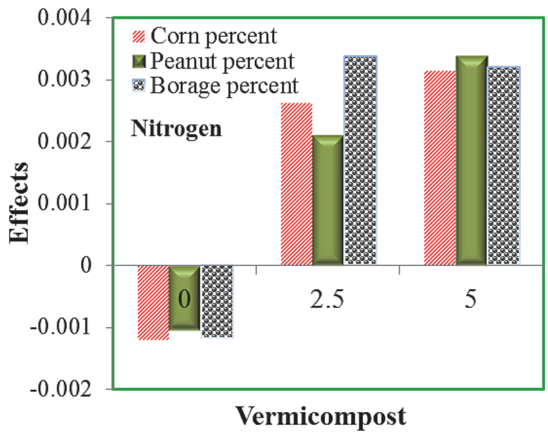

Fig. 4. The effects of vermicompost on nitration in intercropping

Phosphorus

Fig. 5 illustrates the effects of vermicompost in intercropping for different values of vermicompost (i.e., 0, 2.5, and 5 ton/ha) on phosphorus in the soil. The results of Fig. 5 showed that the minimum amount of phosphorus in the soil was obtained with the non-use of vermicompost and the

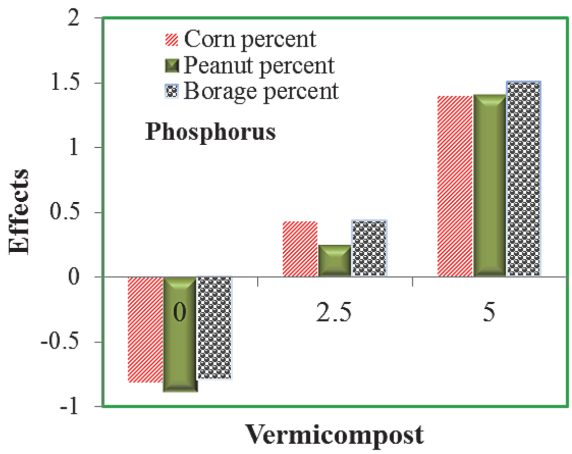

Fig. 5. The effects of vermicompost on phosphorus in intercropping

highest amount was obtained from the treatment of five tons per hectare.

Organic carbon

The effects of different levels of vermicompost in intercropping in 0, 2.5, and 5 ton/ha of vermicompost on the organic carbon content are shown in Fig. 6. The results from Fig. 6 demonstrated that the soil organic carbon content increases by increasing the amount of vermicompost. According to the following equation that the proportion of organic matter is 1.72 times the amount of soil carbon; therefore, by increasing the amount of organic carbon in the soil, the main part of organic matter increases. In addition, if the plant produces more debris, the soil organic matter, and subsequently, the soil organic carbon content will increase.

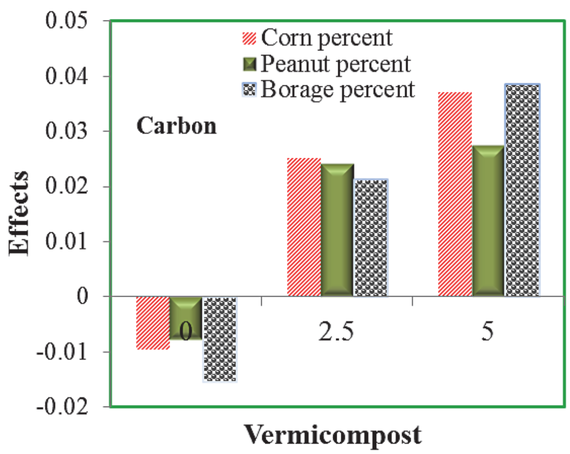

Fig. 6. The effects of vermicompost on carbon in intercropping

Sodium

Fig. 7 illustrates the effects of different amounts of vermicompost in intercropping for three levels of vermicompost on soil sodium. As observed, the minimum amount of sodium in the treatment of vermicompost was found in borage. The increase in acidic soil conditions reduces sodium absorption; usually sodium has a strong propensity to be absorbed in soils with alkaline conditions. In the treatment, the non-use of organic fertilizer reduces soil acidification and an increased amount of sodium in the soil in this condition reduces the amount of organic fertilizer. In other words, by increasing the amount of organic fertilizers due to increased cation exchange capacity and high special levels of organic fertilizer, sodium is absorbed by the soil. In addition to increased soil aeration and an increase in the permeability of the soil with organic fertilizer, the sodium washed from the soil will increase.

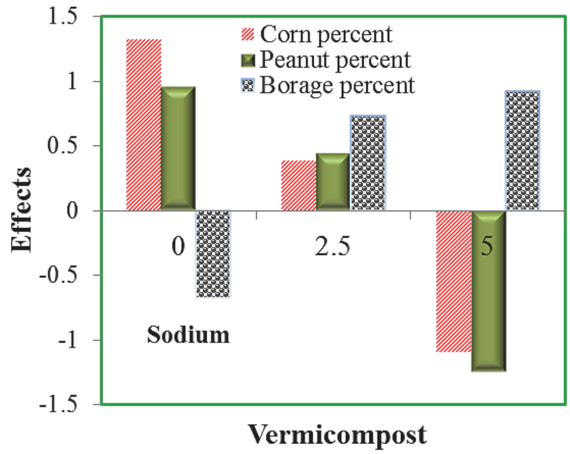

Fig. 7. The effects of vermicompost on sodium in intercropping

Discussion

The optimum condition of the percentage of intercropping based on peanut, borage, and corn for three levels of vermicompost (i.e., 0, 2.5, and 5 ton/ha) is discussed to improve the best conditions for the chemical properties of soil elements as follows:

Nitrogen

The soil nitrogen constant with respect to different planting patterns in 50% borage + 50% corn for three levels of vermicompost (i.e., 0, 2, and 5 ton/ha) is shown in Fig. 8. It is obvious, that the nitrogen constant was increased by increasing the percentage of the peanut plant in the pattern. An important factor in managing soil is its fer-

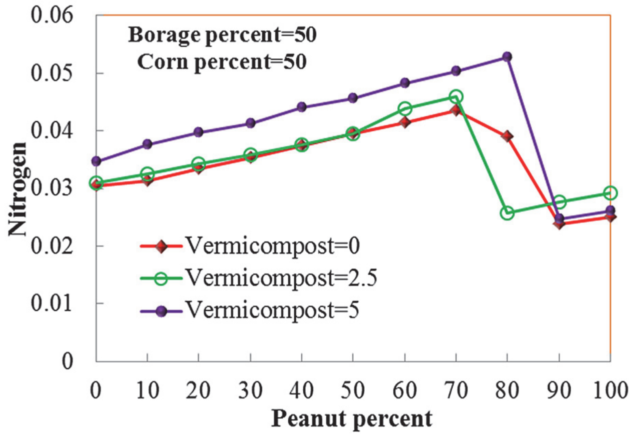

Fig. 8. The effects of planting patterns in intercropping on nitration for different vermicompost

tility, which includes the appropriate density of crops, the use of suitable fertilizer, and other factors. Proper management of nutrients makes the soil fertile by increasing the organic matter (for example: vermicompost). In this regard, the use of vermicompost as an organic fertilizer increases soil nitrogen as an essential element of the soil and the best treatment in all the planting patterns involves the treatment of five tons of vermicompost per hectare.

Vermicompost improves soil structure, soil aeration, and it increases soil microbial activity and soil-moisture capacity by providing the essential nutrients. On the other hand, peanut is a nitrogen-fixing plant in this model, which creates better conditions for nitrogen fixation by increasing vermicompost. Different species in intercropping with resources use and niche various, leading to resources utilization so that in planting of cereal with legume, that legumes use atmospheric nitrogen and there is a transmission system from legumes to cereals (Sing et al., 1996; Karpenstein-Machan and Stuelpnagel, 2000; Hauggaard-Nielsen and Jensen, 2005; Muler et al., 2014; Brooker et al., 2015; Li et al., 2016; Liu et al., 2017). According to Figs. 4 and 5, the highest nitrogen ratio was observed in the following planting proportion: 80% peanut + 50% corn + 50% borage. In this process of modeling after the peanut, an increased proportion of borage in the pattern was more effective than corn in the present proportion of nitrogen in the soil; this issue showed that the proportion of borage can be greater due to corn's higher need for nitrogen. For wheat-corn, soybean-wheat, corn-broad bean intercropping, simplification was observed. Broad bean increased the nitrogen and phosphorus absorption in corn-broad bean intercropping, and it was concluded that intercropping with higher efficiency caused a reduction in nutrition consumption and in the amount of nitrate in the soil profile (Zhang and Li, 2003). Nitrogen deficiency is very common in arid and semiarid regions. In order to increase soil fertility, therefore, the use of organic fertilizers causes a gradual release of mineral elements in soil; nitrogen waste is minimized. The lasting effect of a combination of a recently-established grain legume-barley intercropping system on the fertility status of a sandy clay loam soil during the subsequent cultivation of durum wheat was clearly observable. This finding was especially noticeable in terms of the significantly higher total organic C and N pools, which were also functionally linked to C dynamics and the soluble N forms' release (Scalise et al., 2015).

Phosphorus

The planting patterns of peanut with 50% borage and 50% corn patterns in different values of vermicompost (i.e. 0, 2.5, and 5 ton/ha) on phosphorus in the soil are illustrated in Fig. 9. The results demonstrate that the phosphorus in the soil may increase with an increase in vermicompost and peanut percentage in a range between 0-60 percent.

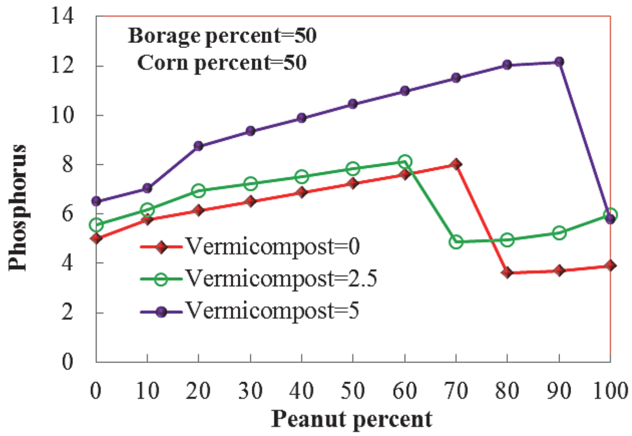

Fig. 9. The effects of planting patterns in intercropping on phosphorus for different vermicompost

Organic fertilizers contain a lot of organic matter and decomposition of this organic matter causes the production of acid and phosphate deposits in soils, which are very intense because of the high sodium content in arid regions and because of the decreased absorbability of sodium in the soil; the decomposition of organic matter and acid production reduces the reaction of the soil, and it will increase the ability to absorb phosphorus. Further increasing soil organic matter improves soil aeration and the optional activity of aerobic heterotrophic bacteria increases because the activity of these bacteria may increase by increasing soil aeration and the amount of oxygen; this activity may increase acid production in the soil. The moisture content of soil affects phosphorus absorption and by increasing the organic matter moisture, the uptake of phosphorus is increased; this will increase the diffusion of phosphorus in the soil. Among the culture proportions, the highest amount of phosphorus was associated with the following planting pattern: 90% peanut + 50% corn + 50% borage. With the increase of peanut proportion in the planting pattern at a proportion greater than 90%, the soil phosphorus levels decreases; this is due to an increase in intra-species competition compared to the competition between species. In the mixed culture of wheat and chickpea, earthworms changed the interaction between the species by reducing the competition for nutrients. Facilitation (positive plant-plant interactions) was observed for the root biomass and P acquisition in the presence of earthworms. In this experiment, earthworms could be seen as “troubleshooters” in the plant-plant interaction as they reduced the competition between the intercropped species (Coulis et al., 2014). A facilitation of these two plants was also observed in another study (Betencourt et al., 2012).

Corn is a four-carbon plant that requires a lot of food and depletes the soil’s macronutrients. Therefore, borage as a medicinal plant indicates the greater impact on the planting pattern in increasing the amount of phosphorus in the soil. The soils of Iran are mostly alkaline and the soil pH value has an influence on nutrient presence and uptake in the soil. The reported rhizosphere, P availability, microbial properties, and mycorrhizal colonization were affected by intercropping and the soil P status. A systematic increase in P availability (Olsen et al., 1954) and microbial biomass occurred in the rhizosphere of intercrops and sole crops compared to the corresponding bulk soil (Tang et al., 2016). With a faster development of canopy and increased plant height in comparison to the other plants, corn increases moisture in the root zone and attracts more phosphorus. Phosphorus also increases the growth of the upper organs that improves the efficiency of light in intercropping, which, in turn, improves the absorption of phosphorus. The lack of vermicompost reduces soil phosphorus and the amount of this element increases in the five-ton vermicompost treatment. In neutral and alkaline soils, legumes are assumed to increase inorganic P availability by rhizosphere acidification due to N_2 fixation, which benefits the intercropped cereal. The cereal, through rhizosphere alkalization, may also enhance P uptake and the growth of the intercropped legume (Betencourt et al., 2012). The results showed that root contact modified the microbial communities and the dominant microbial species in the intercropped rhizosphere, thereby contributing to increased P uptake during intercropping in acidic soils (He et al., 2013).

Organic carbon

The planting patterns of peanut with 50% borage and 50% corn patterns in 0, 2.5, and 5 ton/ha vermicompost on the organic carbon content are shown in Fig. 10. As observable, the soil organic carbon content significantly increases by increasing the amount of vermicompost beyond 2.5 ton/ha. In addition, if the plant produces more debris, the soil organic matter, and subsequently, the soil organic carbon content will increase. Peanut plant has greater root volume, and leaves and stems debris in comparison to two other plants. In examining the interaction of vermicompost and the culture proportion, borage has indicated more impact in increasing the soil organic carbon content than the two other plants in the group in the presence of 5 tons of vermicompost per hectare. When two species with different growth characteristics are involved in intercropping, they have the lowest tendency to compete with each other; these results in the increase of efficiency in resource-use and intercropping performance in comparison to sole cropping (Neumann et al., 2009). Improving the efficiency of nutrition consumption in intercropping in comparison with sole cropping may be described as follows: two different species do not compete for equal nutrition sources; phenology and root structure of the plants led to the capture of resources (Vandermeer et al., 1989; Hauggaard-Nielsen and Jensen, 2001; Hauggaard-Nielsen et al., 2001). These results are substantiated by the report of Sujatha and Bhat (2010), which indicated that the application of vermicom-

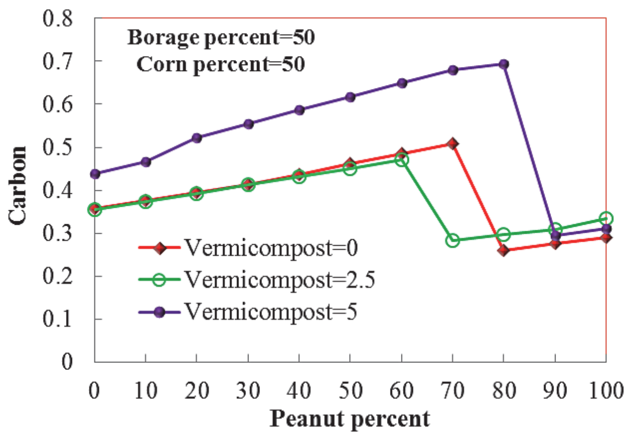

Fig. 10. The effects of planting patterns in intercropping on carbon for different vermicompost

post and FYM significantly increased the Soil Organic Carbon (SOC) content by 38-54% in 2008 from their initial levels in 2004. In the diagrams of culture pattern, 80% peanut + 50% corn + 50% borage is the best pattern in terms of increasing the carbon content of the soil.

The higher concentration of nitrogen in the soil and absorption by plants leads to higher carbon absorption. Increased organic matter in the soil increases the cation exchange capacity. By improving the absorption efficiency of environmental resources, temperature, and humidity in intercropping, the mineralization of organic compounds will be well done. This issue increases the SOC content according to the needs of the three plants during the growing season. Borage leaves or its flowering shoots, and in some sources, the use of its flowers have been mentioned as borage needs less food than the other two plants, it has a shorter growth season, it contains phenolic and mucilage compounds in the flowering shoot, and the amount of carbon absorbed from the soil is lower. However, corn and peanut, owing to longer growing seasons, grain protein syntheses, and higher accumulations of dry matter, absorb more carbon from the soil. Therefore, borage's role in increasing the amount of organic carbon is more important than the two mentioned plants. For okra, cowpea, and corn intercropping, corn occupied a more external surface than okra by forming a crown layer and cowpea occupied a less external surface in the absorption of radiation. Corn, which was at a greater height, was, therefore, more competitive with okra. Nevertheless, cowpea/okra intercropping had more beneficial effects than corn/okra intercropping; due to a higher LER and improved soil fertility legumes mixed with okra was favored (Muoneke et al., 1997). In addition, the results indicated that the plant carbon allocation below ground was altered in the presence of a different neighboring species. The increase of plant diversity probably enhances the soil microbial activity and hence leads to the turnover of the plant-derived carbon in the soil (Fan et al., 2008).

Sodium

Fig. 11 illustrates the different planting patterns in the 50% borage + 50% corn planting pattern for three levels of vermicompost on soil sodium. It can be observed that borage has had a greater impact in reducing soil sodium than vermicompost. Different plants have different capabilities in the extraction of potassium from the soil, and under the same conditions, grasses are more capable in extracting potassium from the soil than legumes (Srinivasarao et al., 2006). There is an increase in the selective absorption of potassium for tolerant species of plants in terms of increased salinity, which indicates the plant's mechanism in maintaining the ratio of potassium in the intracellular sodium level (Zhu, 2003). The best culture pattern in terms of the lowest amount of sodium is about 80% peanut + 50% corn + 50% borage as well as the consumption of five tons of vermicompost per hectare. Although the usage of vermicompost results in an increase of soil fertility by improving the physical, chemical, and biological features of soil, and finally results in improving plant growth, using highly concentrated vermicompost may disrupt plant growth because of the high concentration of dissolved salt in it (Lim et al., 2015).

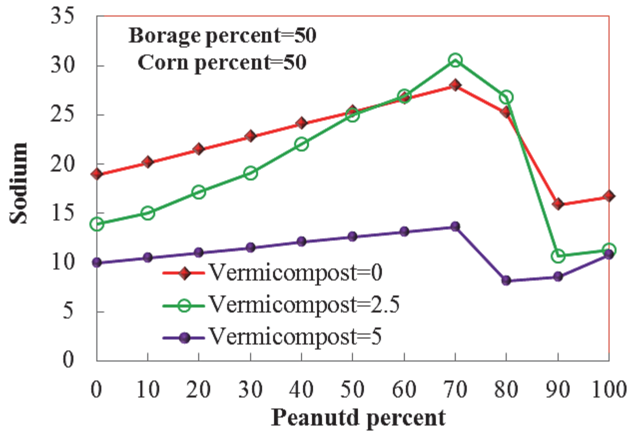

Fig. 11. The best planting pattern based on increased soil sodium in intercropping using nonlinear modeling

The presence of the nutrients nitrogen, phosphorus, potassium, calcium, and magnesium as well as microelements demonstrates the benefits of using vermicompost over other organic fertilizers (Atiyeh et al., 2000a, 2000b). The borage plant had a semi-node root that was buried in the ground at a depth of 50 cm such that its root system increased resistance to drought and salinity, and improved its ability to absorb ions such as sodium, potassium, chlorine, calcium, and magnesium. Selection power is important on the uptake. Since the borage plant had a root area that was smaller than the roots of the other two plants in the mixture, the exchange capacity was lesser. Most salinity is in non-use of vermicompost that borage as a conditioner of saline and alkaline soil reduces the amount of sodium. They are about 30% efficient in borage, and in addition, leaves and flowers of the plant have dipotassium. The increased amount of vermicompost up to five tons per hectare increases the nitrogen and the potassium uptake in borage. In addition, with increasing borage in the pattern, plant debris caused an increase in the sodium content of the soil.

Conclusions

The optimum planting patterns in intercropping are one of the most important decisions of selecting a suitable culture pattern to improve the soil fertilities in the desert region. Generally, the nonlinear mathematical models can be used to evaluate the organic fertilizers of the soil element in intercropping. In order to evaluate the optimum planting patterns from three plants, including corn, peanut, and borage with three levels of vermicompost (as 0, 2.5, and 5 tons per hectare), datasets are examined based on nine intercropping patterns (including 50% corn + 25% peanut + 25% borage, 100% corn + 50% peanut + 50% borage, 40% corn + 30% peanut + 30% borage, 100% corn + 75% peanut + 25% borage, 60% corn + 20% peanut + 20% borage, and 100% corn + 25% peanut + 75% borage) at the Zahak station, which is located in the Institute of Zabol University in Iran. The experimental station in Zahak is located in a region of a very hot climate with a maximum temperature 46°C in the year as well as dry weather with 3,200 sunshine hours and about 50 mm of rainfall (seven months without rainfall); in the region, the potential for evapotranspiration is more than 5,000 mm with 120-day winds. A nonlinear mathematical model-based response surface method is developed to apply the prediction of the intercropping patterns. The nonlinear model is established based on two-repression steps using exponential and high-order polynomial basic functions. The hyperbolic tangent sigmoid transfer function is used for mapping the first calibration stage to implement the input data in the second calibration stage. The proposed nonlinear model showed accurate predictions for soil elements based on the different intercropping methods and vermicompost. The prediction results of the nonlinear model were used to find the optimum planting patterns in different vermicompost levels that provided the following results:

The results revealed that vermicompost increased soil fertility by improving the soil structure and the moisture-holding capacity of soils, which increased water absorption and retention, releasing many minerals and nutrients for growing plants. Vermicompost can play an important role in soil element change, especially in the dry area of Zabol and similar areas around the world. In this experiment, suitable fertilizations of soil nutrition with increases in carbon, nitrogen, and phosphorus improved using five tons of vermicompost per hectare; peanut as the nitrogen-fixing agent in the intercropping pattern produced a positive effect on the soil properties. By increasing the percentage of the peanut plant in the intercropping pattern, the chemical soil properties, such as carbon, nitrogen, and phosphorus, were increased for this very dry region. In addition, it can be concluded that the intercropping pattern of 80% peanut + 50% corn + 50% borage alongside the usage of five tons per hectare of vermicompost can improve the soil fertility in dry areas.

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