Computers and Electronics in Agriculture 122 (2016) 218–224

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Assessment of soil elements in intercropping based on mathematical modelling

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A R T I C L E I N F O

Article history:
Received 26 April 2015
Received in revised form 3 January 2016
Accepted 26 January 2016
Available online 17 February 2016

Keywords:
Intercropping
Mathematical modeling
Tillage
Soil fertility

A B S T R A C T

Restoring diversity in agricultural ecosystems and its effective management is one of the key strategies in sustainable agriculture. Intercropping as an example of sustainable agriculture systems, follows objectives, such as the ecological balance, more efficient use of resources, and increase soil fertility. Investigating soil elements in intercropping is a basic criterion for selecting the type of intercropping and increasing soil productivity. This paper presents a nonlinear mathematical model for evaluating the elements of the soil that resulted from intercropping Roselle and Mung bean. To estimate the amount of carbon, nitrogen, and sodium, the independent variables including different proportions of intercropping (100%, 50%, 25%, and 0% Roselle) and type of tillage (No tillage, Reduce Tillage, and Conventional tillage) have been used in elements based on a nonlinear form mathematical expressions. Roselle was selected for intercropping with Mung bean that was evaluated in three different soil tillage methods. Elements have been calibrated in two phases and based on the presented non-linear mathematical model based on an iterative procedure. In the first phase, the soil temperature was fitted based on the type of tillage and intercropping ratio and in the second phase, it was fitted based on the fitted temperature and type of tillage and several intercropping ratio. Changes in the nutrient with respect to sensitivity analysis of the presented nonlinear mathematical model were assessed based on the intercropping type at different tillage. The results from the nonlinear modeling showed that with increase in Mung bean in intercropping, the contribution of soil organic carbon (SOC) and nitrogen are increased and the carbon: nitrogen (C/N) ratio is decreased. Comparing no-tillage systems in terms of rates of soil organic carbon and nitrogen is more than other tillage systems.

1. Introduction

To date, the increased degradation of water, soil resources, and environment due to indiscriminate use of chemicals and conventional food production in the world, brought about the attention in sustainable agriculture and encourage researchers in this field (Lithourgidis et al., 2011; Goulding et al., 2008). Several studies which have been conducted on agricultural management techniques, such as the type of tillage (Clapp et al., 2000), fertilization (Huang et al., 2010), the return of crop residue (Blaier et al., 2006), and crop rotation (Koocheki et al., 2004) represent a significant effect on the amount of soil organic carbon. Intercropping is one aspect of sustainable agriculture which has been proposed by increasing the number of species per unit area as a solution to enhance the advanced agricultural production (Bodner et al., 2013). The use of nitrogen-fixing legumes in intercropping leads to the return of a lot of material absorbed by plants to the soil and increase soil fertility (Hauggaard-Nielsen et al., 2003; Schipanski et al., 2010; Monneveux et al., 2005). Prasad and Brook (2005) stated that due to various circumstances of agro-ecosystems in intercropping legumes and cereals and improve resource utilization in a particular time and place, the amount of carbon and nitrogen increases in the soil. Dyer et al. (2012) showed that increase in soil organic carbon in grass-legume intercropping is more than the grass monoculture with respect to statistical analysis with a significance level of 5%. Ghamari Rahim et al. (2011) showed in the intercropping of maize and soybean that the soil organic matter on the level of 1%, had a significant difference in different intercropping systems so that the highest percentage of soil organic matter was in soybean monoculture and the lowest percentage of carbon was in the treatment of maize monoculture. Kandel et al. (1997) in investigating intercropping vetch (*Vica villosa*) with sunflowers based on statistical analysis showed that intercropping as compared to monoculture, due to increased soil cover, leads to reduce erosion and increase in the amount of carbon and nitrogen of the soil. In addition, it was found out that greater distribution of nitrogen in the soil via nitrogen fixation and low

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http://dx.doi.org/10.1016/j.compag.2016.01.036
0168-1699/

leaves falling down of legumes, will improve soil fertility and improved growth of grasses. The amount of soil organic carbon increases in grass-legume intercropping and creates favorable conditions for crops, such as weed control and optimal plant density, increase the efficiency of intercropping to increase the nutrient and improve soil fertility after harvesting (Zhang et al., 2012; Sheng-Wei et al., 2012). Better absorption of elements and improvement in soil fertility in intercropping compared to monoculture was reported by Inal et al. (2008) on peanuts and corn and Gil and Fick (2001) on alfalfa and grass. The conservation of tillage operation in crop production systems to manage and maintain the plant debris in which at least 30% of the land surface remain decayed by plant debris after intercropping (Limousin and Tessier, 2007). Kasper et al. (2009), based on a statistical analysis, showed that the organic carbon, nitrogen, and carbon:nitrogen (C/N) ratio are related to tillage method such that conservation tillage had less damaging effect on soil properties. Therefore, this type of tillage can have a good potential to increase carbon and nitrogen. Increased elements and improved soil fertility in tillage at least compared to conventional tillage, have been reported by other investigators (Verhulst et al., 2010; Weyers and Spokas, 2014; Ismaili et al., 2015). On the other hand, the conventional tillage is faced with serious challenges as a factor that has accelerated soil erosion, reduced carbon storage, and involved in the degradation of soil structure. Maintaining an adequate amount of crop residue has been emphasized as a relevant solution to deal with threats to soil quality (Lithourgidis et al., 2011). As mentioned earlier, most research on the study of culture and tillage type has been evaluated based on statistical analysis. In this paper, according to the procedure of modeling, the effects of elements' sensitivity to the type of tillage and proportion of intercropping components were evaluated and a proper equation was presented for the sensitivity of intercropping that the effect of tillage on the decline and increase of nutrient has been calculated and which led to appropriate decisions on the basis of the soil fertility criterion.

A nonlinear relationship was used in this type of modeling. Soil temperature as an influencing parameter has been modeled given the type of tillage and Mung bean-Roselle intercropping shows that soil temperature was also used to investigate soil elements. Based on three types of tillage (no-tillage, reduce tillage, and conventional tillage), the effect of intercropping on soil nutrient has been evaluated based on the provided mathematical model. Therefore, this research has 6 sections and the second section presented the harvest location and how to hold the experiment. In the third section, the nonlinear modeling based on the least squared method by an iterative mathematical procedure was presented. In the fourth section, non-linear models for soil temperature and nutrient based on the type of tillage and intercropping were explained. The fifth section provided the discussion of results to change of culture on soil elements and finally, conclusions are expressed based on the assessment of nutrient due to the non-linear modeling.

2. Materials and methods

Zahhak city's geographical position is 61° 41 min east and latitude 30° 54 min north and at an altitude of 481 m above sea level in Iran country. Given the Köppen climate classification, the region's climate is very warm and with hot and dry summers and based on the Ambrgeh classification, it is also of hot and dry areas. The experimental soil had a Loam-sandy texture. The results of the chemical analysis of soil showed that the soil of the test location has an electrical conductivity of the saturation extract soil of 2.93 dS/m and pH 7.80. The experiment was conducted as split plots in a complete randomized block design with three replications. The main factor which is the type of tillage included the no tillage, reduce tillage, and conventional tillage and the second factor consisted of pure Roselle, pure Mung bean, 50% Roselle + 50% Mung bean, 75% Roselle + 25% Mung bean, and 25% Roselle + 75% Mung bean. Land preparation was performed in mid-June 2013 and 2014 based on the three types of operation systems including plowing, plowing without tillage (no-plow), reduce plow (disc), conventional plowing (plow and disc). Plants were grown in plots with dimensions of 2×3 m where the distance between rows was 40 cm from each other (All treatments were cultured in a row of Roselle and a row of Mung bean). The distance between rows was the same, but the density in each row was different. Planting proportions were implemented via variation in bush density (the distance between two bushes in a row) and constant distance between two rows (40 cm). Walkley and Black (1934) method was used to measure carbon (%). Nitrogen (%) was measured using the Kjeldahl Method and sodium (ppm) was measured using the soil extraction method with a flame photometer type of Corning 405. Thermometers special for France were applied to measure the temperature of the soil (Thermometer Dial Deep Frying). In order to achieve this, the thermometer was placed between rows at a depth of 15 cm and the soil temperature was measured in the different treatments such that the statistical results of the different perceptions are listed in Table 1.

On the basis of various types of intercropping and three types of tillage, three samples were taken in each culture that consistent with the results of the laboratory, the average of three samples of each culture medium is listed in Table 2.

As shown in Table 2, the no-tillage systems have more carbon and lower nitrogen as compared to other tillage systems. In the monoculture of Mung bean when compared with monoculture of Roselle, the amount of carbon and nitrogen increases, as well.

3. Modeling procedure

Based on the results in Table 2, correlations between nutrients and soil temperature are presented in Table 3 according to the type of tillage and various intercropping proportions of Roselle.

The correlations presented in Table 3 for the independent variables (tillage and planting ratio) and dependent variables of temperature and soil nutrient (sodium, carbon, and nitrogen) are calculated as follows (Willmott and Matsuura, 1998):

$$\rho_{Y,X} = \frac{\sum_{i=1}^{n}(y_i - \overline{Y})(x_i - \overline{X})}{\sqrt{\sum_{i=1}^{n}\left[y_i - \overline{Y}\right]^2 \sum_{i=1}^{n}\left[x_i - \overline{X}\right]^2}} \quad (1)$$

where $\rho_{Y,X}$ is the correlation coefficient between soil properties qualitative variables such as carbon and nitrogen and sodium (Y)

Table 1
Results of statistical variables nutrient and soil temperature.

Depended variable	Minimum	Maximum	Mean	Standard deviation	Number of samples
Carbon (%)	0.34	1.8	1.07	0.35	90
Nitrogen (%)	0.0293	0.16	0.22	0.03	90
Na (ppm)	14.8	110.62	62.71	30.34	90
Soil temperature (°C)	16.2	24.6	20.4	2.1	90