Fertilization Forecasting Algorithm Based on Improved BP Neural Network

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Abstract. In this paper, we consider a fertilization forecast algorithm based on improved BP neural network. By analyzing traditional single fertilization forecast algorithm, we find that they are too simple, lack of network training and cannot take into account the impact of different nutrients. Then, we consider an improved BP neural network algorithm, which is based on the Lagrangian multiplier method to optimize the BP neural network and nutrient balance method by weighted combination algorithm. The simulation results show that the improved method can accurately guide the amount of fertilizer, only a small amount of learning data.

Keywords: Fertilization forecast · BP neural network
Nutrient balance method · Weighted combination method

1 Introduction

In recent years, excessive use of chemical fertilizers caused a lot of waste of fertilizer and irreversible damage to our environment [1]. At present, our government has realized that the important of precision fertilization in increasing yield and protecting ecology [2]. With the application of big data in the field of agriculture, the research of fertilization forecasting algorithm becomes a research focus.

The current solution for fertilization forecasting is based on linear or single variable [3]. However, both of these solutions exist interaction. In [4], Wang et al. using the improved BP neural network algorithm to predict the amount of fertilizer, the K-means clustering is used to optimize the weight of the neural network to be integrated by the Lagrangian multiplier method.

In this paper, we consider an improved BP algorithm. Firstly, calculate the predictive value of BP neural network and nutrient balance method respectively. Then, we utilize weighted combination method based on prediction error square minimum. Taking into account the interaction between fertilizers and increasing the factors of light time and rainfall. In the case of less learning samples, more accurate fertilization predictions can be made.

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The rest of the paper is organized as follows. In Sect. 2, we provide system model for fertilizer forecast. We provide a single forecast algorithm model, including BP neural network and nutrient balance method in Sect. 3. Section 4 provides the improved algorithm model. We utilize weighted combination method based on prediction error square minimum. In Sect. 5, we show the performance of our algorithm by simulation.

2 System Model and Problem Formulation

The factors that affect crop yields are not only nitrogen, phosphorus and kalium, but also light time, chlorophyll content, precipitation, water content in different depths, soil conductivity. These factors exist complex interaction rather than linear. Problem model, as shown in Fig. 1. Note that N, P and K represent the content of nitrogen, phosphorous and potassium, W represents the water content in different depths. SC and CC represents soil conductivity and chlorophyll content, L represents light time. FN, FP, FK and FW represent the fertilization forecast value of nitrogen, phosphorous, kalium and water. In this paper, we should research an algorithm to find the relationship between soil parameters and fertilization. The purpose of our algorithm is that could calculate the amount of water that should be irrigated when light time hadn't achieve the best.

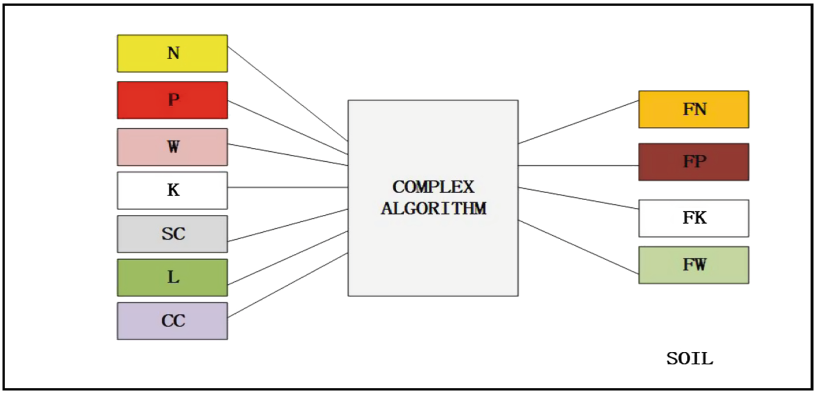


Fig. 1. Problem mode

Our problem formulation deals with complex relationship between soil parameters and fertilization. We propose an improved algorithm for BP neural network algorithm, which is based on the Lagrangian multiplier method to optimize two kinds of single prediction algorithms by using weighted combination method to reduce the prediction error of fertilization lowest. Figure 2 shows the improved algorithm model. The key to solving this problem is to determine the weights of the coefficients l_1 and l_2.

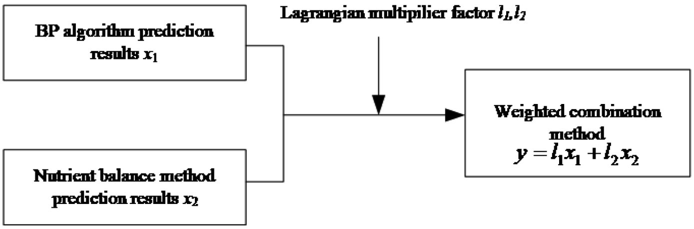


Fig. 2. The improved BP neural network algorithm model

3 Single Forecast Algorithm

3.1 Nutrient Balance Method

The nutrient balance method proposed by Truog in 1960s. The nutrient balance method is used to estimate the amount of fertilizer according to the difference between target yield and soil supply [5]. The formula for the amount of fertilizer is (1)–(4). In the formula, y is the amount of fertilizer, m is the amount of fertilizer required for the soil, g is the amount of fertilizer required for the soil, k is the amount of fertilizer required for crop units, z is the target yield, λ is the effective nutrient correction coefficient for soil, x is the soil nutrient value, μ is the nutrient content in the fertilizer, η is the fertilizer utilization, q is the amount of the element absorbed by the lack of nutrient area, k is based on the statistical analysis of agricultural experts to determine the data [6].

$$y = \frac{m - g}{\mu\eta} \tag{1}$$

$$m = kz \tag{2}$$

$$g = 0.15\lambda x \tag{3}$$

$$\lambda = \frac{q}{0.15x} \tag{4}$$

However, the method requires a large number of parameters to be calculated. It is difficult to effective management of fertilization parameters.

3.2 BP Neural Network Algorithm

The BP algorithm was proposed by D. Rumerlhart and J. McCelland in the mid-1980s [7]. BP algorithm is divided into learning and forecasting two parts. Figure 3 is the neural network learning part of the schematic diagram.

Firstly, we put given data of the test group into input layer parameters, put forecast data of the test group into output layer (tutor vectors). Then, input layer parameters pass through the hidden layer of complex calculated, the results will be given to the output. Compared with tutor vectors, we put error feedback to hidden layer. Last, the hidden layer of neurons to adjust. BP neural network consider the influence between fertilizes

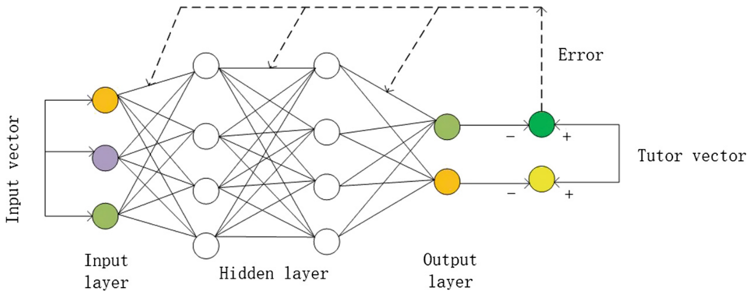


Fig. 3. The neural network learning part of the schematic diagram

and raining. But BP neural network algorithm has disadvantage of slow convergence, the number of hidden layer nodes is difficult to determine and different value has different neural network.

4 Improved Algorithm Model

4.1 Weighted Combination Method

Weighted combination method is an evaluation function method, which is based on the importance of each goal to give it corresponding weighted coefficient, and then find the solution method of multi-objective programming for linear combination [8].

Suppose that a set of observations for a given object is $x_t(t = 1,2,\ldots,N)$. It exists m kinds of single prediction methods. Assume that the predicted value of the i^{th} single prediction method is $x_{it}(i = 1,2,\ldots,m)$. $e_{it} = x_t - x_{it}$ is predicts error of i^{th} single prediction. $l_i(i = 1,2,\ldots,m)$ is weighted coefficient of i^{th} single predicted method, $\sum_{i=1}^{m} l_i = 1$.

Weighted combination predicted model is (5) and its predictive value is y_t. Formula (6) and (7) are respectively the prediction error and the prediction error squared sum. In it, e_t is prediction error, J is prediction error squared sum.

$$y_t = \sum_{j=1}^{m} l_i x_{it} = l_1 x_{1t} + l_2 x_{2t} + \ldots + l_m x_{mt} \quad (5)$$

$$e_t = x_t - y_t = \sum_{i=1}^{m} l_i e_{it} \quad (6)$$

$$J = \sum_{t=1}^{N} e_t^2 = \sum_{t=1}^{N} \sum_{i=1}^{m} \sum_{j=1}^{m} l_i l_j e_{it} e_{jt} \quad (7)$$

Therefore, the solution of the optimal weight of the weighted combination forecast is the solution of the formula under the objective of the sum of the squares of errors. In this paper, the improved algorithm involves two kinds of single prediction algorithms (BP neural network algorithm, nutrient balance method). Formula reduced to (8) can be solved the value of l_1 and l_2.

$$\begin{cases} min\, J = \sum_{i=1}^{N} e_t^2 = \sum_{t=1}^{N} \sum_{i=1}^{2} \sum_{j=1}^{2} l_i l_j e_{it} e_{jt} \\ \sum_{i=1}^{2} l_i = 1 \end{cases} \tag{8}$$

4.2 Lagrangian Multiplier Method

The lagrangian multiplier method is a method of solving the extreme value of a function whose variables are limited by one or several conditions [9]. In this paper, we use the Lagrangian multiplier method to find the minimum value of the function $J = \sum_{i=1}^{N} e_t^2 = \sum_{t=1}^{N} \sum_{i=1}^{2} \sum_{j=1}^{2} l_i l_j e_{it} e_{jt}$ when the condition $\sum_{i=1}^{2} l_i - 1 = 0$ is satisfied.

$$\begin{cases} min\, J = L^T EL \\ R^T L = 1 \end{cases} \tag{9}$$

$$L = L^T EL + \lambda\left(R^T L - 1\right) = 0 \tag{10}$$

$$L^* = \frac{E^{-1}R}{R^T E^{-1} R} \tag{11}$$

$$J^* = \frac{1}{R^T E^{-1} R} \tag{12}$$

In order to simplify the calculation, let $L = (l_1,l_2)^{\mathrm{T}}$, $R = (1,1)^{\mathrm{T}}$, $E_i = (e_{i1},e_{i2},\ldots, e_{iN})^{\mathrm{T}}$. L is the column vector of the Lagrangian multiplier weighting factor. E_i is the column vector of predicted error of i^{th} predictive algorithm. Let $E_{ij} = E_i^T E_j (i = 1,2, j = 1,2)$, $E = (E_{ij})_{(2\times 2)}$. (8) can be reduced to (9). (10) is Lagrangian multiplier formula. L is derived and set to zero. The optimal solution $L*$ and the optimal objective function $J*$ is the simultaneous solution equations.

5 Simulation Results

This paper uses MATLAB 2014b version for simulation [10]. Table 1 is part of the standard data measured over years of testing. Among them, columns 1 to 10 are data for monitoring in the soil, columns 11 to 14 are the best fertilizer application amounts.

The optimum nitrogen fertilizers, phosphate fertilizers and potash fertilizers were compared with those of 30 groups before and after the improvement. The accuracy of the fertilization was improved before and after the improvement. Figure 4 is a comparison of the prediction accuracy of the improved and pre-improved fertilization.

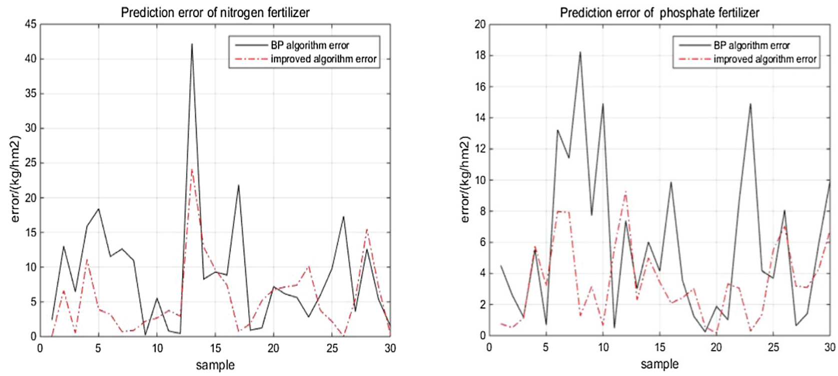
In Fig. 4, it indicates the difference between BP neural network and improved BP neural network algorithm. Figure 4(a) compares the prediction error of nitrogen fertilizer. Sample 18 to 28, improved algorithm prediction results are similar to early algorithm. However, the prediction error of Nitrogen is 4.2% lower than the BP algorithm. The peak error from 43 down to 24. Figure 4(b) compares the prediction

Table 1. Part of the standard data measured over years of testing

No.	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Yield (kg)	Light time (h)	Water content in 10 cm	Water content in 20 cm	Water content in 30 cm	Rainfall (mm)	Chloro-phy11 content	FW (kg hm^{-2})	FN (kg hm^{-2})	FP (kg hm^{-2})	FK (kg hm^{-2})
1	101.5	9.12	199	7713	9.9	53.43	49.99	37.67	55.78	3.34	27.89	160	20	35
2	92.79	11.56	186	7760	9.99	46.74	43.3	30.98	49.09	2.94	24.54	160	20	37
3	109.6	10.1	191	8361	10.9	46.6	42.12	29.8	48.95	2.93	24.47	160	20	40
4	107.42	14.8	193	8038	10.01	43.26	39.86	27.54	45.61	2.73	22.08	158	14	35
5	99.02	15.78	196	7078	10.23	44.57	41.13	28.81	46.92	2.81	23.46	158	14	35
6	107.73	17.26	203	9092	9.9	46.37	42.93	30.61	48.72	2.92	24.46	178	14	40
7	104.3	20.98	202	9192	9.78	45.51	42.07	29.75	47.86	2.87	23.36	170	14	40
8	199.27	15.98	199	10508	10.13	47.65	44.21	31.89	50	3.21	25	195	24	63
9	146.96	16.38	210	8741	10.21	47.78	44.34	32.02	50.13	3.02	25.06	179	24	42
10	146.96	21.56	239	8502	9.89	39.74	36.3	23.98	42.09	3.31	21.04	168	20	35
11	145.72	13.14	188	9070	11.01	52.74	49.3	36.98	55.09	2.94	0	189	28	48
12	118.94	7.56	192	7383	10.34	46.65	43.12	30.89	49	2.93	24.5	155	28	39
13	127.66	7.16	181	9304	9.99	46.54	43.21	30.8	48.89	3.06	24.44	189	26	45
14	129.53	6.56	173	8510	11.01	48.7	45.28	32.96	51.05	2.64	25.52	152	27	47
15	141.05	9.61	176	6985	9.57	41.68	38.24	25.92	44.03	2.49	22.01	147	21	37
16	94.34	12.16	187	6332	11.2	39.23	35.79	23.47	41.58	2.81	20.79	156	18	30
17	94.96	14.12	205	6419	10.23	44.57	41.13	28.81	46.92	2.92	23.79	156	18	29
18	99.01	14.42	183	8464	9.9	46.37	42.93	30.61	48.72	2.87	23.46	176	18	40
19	98.71	17.16	199	7696	9.99	45.51	42.07	29.75	47.86	2.43	0	170	18	40
20	110.54	15.3	193	8440	10.9	43.67	40.23	27.91	46.02	1.92	23.93	165	21	37

error of Phosphate fertilizer. The prediction error of Phosphate is 8.3% lower than the BP algorithm. Figure 5 compares the prediction error of Kalium fertilizer. Among all samples, the improved algorithm errors are under 8 and 13% lower than the BP algorithm.

Figures 4 and 5 compares the prediction error of nitrogen fertilizer, phosphate fertilizer and potash fertilizer respectively. The solid line represents the prediction error of the BP algorithm, and the dotted line represents the prediction error of the improved



a. Comparison of prediction error for Nitrogen b. Comparison of prediction error for Phosphate

Fig. 4. Comparison of prediction error before and after algorithm improved

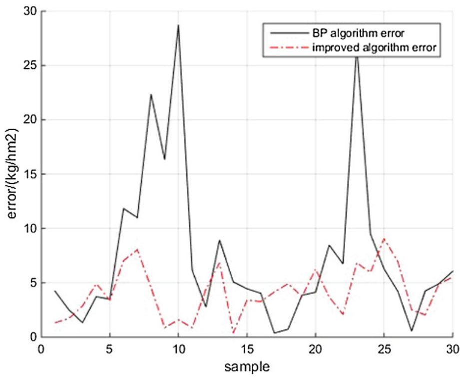


Fig. 5. Comparison of prediction error for Kalium

algorithm. The error comparison standard comes from the actual amount of fertilizer applied from Table 1. The actual amount of fertilizer is a comprehensive consideration of the factors that affect the fertilization of the standard fertilization yield. It can be seen that the improved algorithm is less error-prone than the BP algorithm and is closer to the actual fertilizer. The prediction error is 7% lower than the BP algorithm.

6 Conclusion

In this paper, the advantages and disadvantages of various fertilization forecast methods are compared. Aiming at the shortcomings of BP neural network which requires a large number of learning samples, we proposes a method to improve BP algorithm by weighted combination method. That is, the use of less sample learning data, to carry out agricultural precision fertilizer guidance. It is difficult to see that the accuracy of the optimization algorithm proposed in this paper is improved by 7% through the analysis of MATLAB software programming results. Another breakthrough is that we could calculate the amount of water when light time hadn't achieve the best.

Due to limited time, there are still many shortcomings in this paper. For example, the fertilization cost cannot be taken into account in the fertilization forecasting algorithm, only one crop of maize is predicted, the test sample is small and the variety is single.

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