High Photosynthetic Efficiency and Drip Irrigation under Mulch Applied to Corn in the Northeast Region of China

Jin-hua Gao 1* and Yu Bai 2

1 College of Water Resources and Environmental Engineering, Changchun Institute of Technology, Changchun 130012, China
2 Wuhan University, School of Water Resources and Hydropower Engineering, Wuhan 430072, China

*Corresponding author’s e-mail: zgsherry@sina.com

Abstract: A new type of corn cultivation, high photosynthetic efficiency and drip irrigation under mulch, is presented for the unique geographical and natural conditions in northeast China. The plans of 2014 and 2015 were measured in Lvyuan District, Changchun City. The results show that the influence of the different irrigation lower limits for each growth stage on corn production: tasselling > knee-high > mature; the corn yield of high photosynthetic efficiency and drip irrigation under mulch treating is increased by 47% over traditional treating and the water consumption is increased by 63%. The correlation equation of different additional nitrogen fertilizer amounts, different irrigation lower limits of water content and yield of corn is measured: the interaction between irrigation lower limit at knee-high stage and mature stage is inhibited; the interaction between irrigation lower limit at knee-high stage and different additional nitrogen fertilizer amount is inhibited; the interaction between irrigation lower limit at mature stage and different additional nitrogen fertilizer amount is synergistic. Therefore, it is a useful way to gain higher yield by taking the new type of corn cultivation.

1. Introduction

In recent years, it is very important to ensure food security of China under current situations which are caused by large population, soil erosion, less cultivated land, decline of soil fertility and low fertilizer utilization rate [1]. As one of the main corn producing areas in China, Jilin Province has undertaken the increasing billions yield task in 2020. It has a great potential for high yield as it is located in northeast China which is one of the world’s three golden corn belts [2]. Therefore, better irrigation and fertilization strategies are the main way to increase corn yield [3, 4]. High photosynthetic efficiency and drip irrigation under mulch is a new type of corn cultivation, which can increase corn yield.

There are a lot of researches on drip irrigation under mulch both in China and abroad. It is certain that drip irrigation under mulch can improve yield and quality of corn and develop the agriculture in Heilongjiang by analyzing different quantities and frequencies of irrigation [5]. It can be found that mulching can improve the yield of corn and reduce water loss by comparing different mulching methods’ influence on the yield and efficiency of water application [6]. A reasonable irrigation schedule can regulate the dry matter weight of different organs to improve yield by analyzing different irrigation schedules on the efficiency of water application and biomass indexes in the field experiment of Dumeng County [7]. Drip irrigation under mulch is applied on horticulture and economic crops in abroad as a new planting technique which can keep water and accelerate temperature [8-10]. By
analyzing the influence of different colored mulch on the growth of cucumber, it shows that transparent mulch can get higher soil temperature than black one. The yield of cucumber is increased by combing drip irrigation under mulch \[^{11}\]. Through analyzing 15 year dates of drip irrigation in corn, cotton and tomato, it shows that the frequency and the time of drip irrigation is directly related to the efficiency of water application \[^{12}\].

Research of high photosynthetic efficient cultivation is mainly conducted in Jilin province. High photosynthetic efficient cultivation is a new planting measure which is carried out by the Northeast Institute of Geography and Agroecology under the Chinese Academy of Sciences in Jilin province. There are four following characteristics of high photosynthetic efficient cultivation than conventional methods of corn cultivation: Traditional uniform planting row is changed to wide and narrow planting row; land rests for one year after a cycle of three years; the traditional ridge direction is changed to South West 19°54′. The average yield of 3 years is 13.5% higher than traditional planting patterns in the experiment station of Dehui from 2010 to 2012. The corn fallow rotation plan can promote the nutrient absorption of plants, ensure soil fertility and reduce soil degradation \[^{13}\]. To change the ridge direction and adjust the ridge distance can prolong the illumination time and make full use of solar energy \[^{14}\].

2. Materials and methods

2.1. The resource of main data

The test area, the purple dot in Figure 1, is located in Changchun city, China. The overhead view of the station is shown in Figure 2, whose purple box is presenting the plots after ridge altered. Altered ridge with mulching and emergence is shown in Figure 3 and Figure 4. The test station in the hinterland of the Northeast Songliao Plain, is located 43°7'E, 125°59'N; the average elevation is 210 m and the terrain is flat open; there are four distinctive seasons, the hot rainy seasons and the moderate and dry seasons in this region. The soil in the test area is medium soil with medium soil fertility. The physical and chemical properties of the tested soil are shown in Table 1. Meteorological data is gotten from an arranged watchdog station in the field, the monthly meteorological data of crop growth is shown in Table 2.

| Soil type          | Bulk density (g/cm³) | Allowable water (%) | Available nitrogen (mg/kg) | Available phosphorus (mg/kg) | Available potassium (mg/kg) |
|--------------------|---------------------|---------------------|---------------------------|----------------------------|----------------------------|
| Medium loam        | 1.46                | 25.86               | 134                       | 37                         | 192                        |

Table 2. Monthly weather condition (average of 2014 and 2015) from the watchdog at the agricultural research station during the cropping season

| Year | Month | Minimum temperature (°C) | Maximum temperature (°C) | Rainfall (mm) | Minimum temperature (°C) | Maximum temperature (°C) | Rainfall (mm) |
|------|-------|--------------------------|--------------------------|---------------|--------------------------|--------------------------|---------------|
|      | May   | 9.3                      | 23.6                     | 69.6          | 10.9                     | 22.4                     | 27.9          |
|      | June  | 18.2                     | 27.8                     | 118.7         | 16.8                     | 28.3                     | 29            |
|      | July  | 21.5                     | 33.2                     | 102.5         | 18.9                     | 31.6                     | 3.4           |
|      | August| 19.2                     | 28.4                     | 22            | 18.5                     | 29.1                     | 7.2           |
|      | September | 10.3                   | 24.5                     | 10            | 11.7                     | 23.9                     | 3.4           |
2.2. Pilot scheme

The area of each test field was $6.4 \times 15$ m$^2$ and the distance of combination ridge was 110-50 cm (Figure 5). Corn was sowed in May 1$^{st}$ 2014 and May 1$^{st}$ 2015. Ten treatments were designed in 2014 (Table 3). When field water holding capacity was lower than the number in Table 3 in different stages, we began to irrigate. The irrigation treatments in 2015 were improved by treatments in 2014, and amounts of fertilization were different (Table 4).

Drip pipes were made of polyethylene (diameter was 16 mm) and placed between the plant rows before sowing. The volume of irrigation water for each irrigation time was calculated using the following equation:

$$V = \left(\left(\theta_{FC} - \theta\right) \times D \times Bd\right)/\left(E_a\right) \times A$$  \hspace{1cm} (1)

where $V$ is the volume of water to be applied (L); $\theta_{FC}$ is the target gravimetric soil moisture content (%), and moisture content was measured by oven drying method; $\theta$ is the gravimetric soil moisture content before irrigation (%); $D$ is depth of the root (cm); $Bd$ is bulk density of soil (g cm$^{-3}$); $E_a$ is irrigation efficient and equal to 90% for drip irrigation system; $A$ is the area of test field.
Table 3. Irrigation and fertilizer treatments in 2014

| Year 2014 | Treatment | Knee-high | Tasselling | Maturity | Addition nitrogenous (kg/hm²) |
|-----------|-----------|-----------|------------|----------|-------------------------------|
| I1        | 65%       | 65%       | 65%        |          | 168                           |
| I2        | 85%       | 85%       | 85%        |          | 168                           |
| I3        | 75%       | 75%       | 75%        |          | 168                           |
| I4        | 65%       | 75%       | 85%        |          | 168                           |
| I5        | 75%       | 85%       | 65%        |          | 168                           |
| I6        | 85%       | 65%       | 75%        |          | 168                           |
| I7        | 65%       | 85%       | 75%        |          | 168                           |
| I8        | 75%       | 65%       | 85%        |          | 168                           |
| I9        | 85%       | 75%       | 65%        |          | 168                           |
| I10       | /         | /         | /          |          | 168                           |

Table 4. Irrigation and fertilizer treatments in 2015

| Year 2015 | Treatment | Knee-high | Tasselling | Maturity | Addition nitrogenous (kg/hm²) |
|-----------|-----------|-----------|------------|----------|-------------------------------|
| I1        | 65%       | 85%       | 65%        |          | 150                           |
| I2        | 65%       | 85%       | 75%        |          | 150                           |
| I3        | 75%       | 85%       | 65%        |          | 150                           |
| I4        | 75%       | 85%       | 75%        |          | 150                           |
| I5        | 65%       | 85%       | 65%        |          | 186                           |
| I6        | 65%       | 85%       | 75%        |          | 186                           |
| I7        | 75%       | 85%       | 65%        |          | 186                           |
| I8        | 75%       | 85%       | 75%        |          | 186                           |
| I9        | 70%       | 85%       | 70%        |          | 168                           |
| I10       | /         | /         | /          |          | 150                           |

2.3. Genetic algorithm fitting curves of the relationship between the factors and the yield

Curve fitting has been a concern problem in data analysis process\cite{15-16}, and multi factors equation of traditional agriculture is made by many optimization algorithms\cite{17-18}. Genetic algorithm, proposed in 1975, is a global optimization algorithm based on exchanged chromosome information of species. There is no need to readjust data, and it can reduce the possibility of falling into a local optimal solution.

Three variables power two mathematical model, based on the number of test, has been set up to describe the relationships of different amounts of nitrogen fertilizer, different irrigation lower limits of water content and yield of corn, which is shown as formula(2) in the following:

\[
y = M_1 + M_2X_1 + M_3X_2 + M_4X_3 + M_5X_1X_2 + M_6X_2X_3 + M_7X_1X_3
\]

Where \(M\) is unknown parameters, \(X\) is value of each factor.

The equation is required to normalize before fitting, \(Z_1 = \frac{X_1 - 70}{70}\), \(Z_2 = \frac{X_2 - 70}{70}\), \(Z_3 = \frac{X_3 - 168}{168}\). The transformed equation is as follows:

\[
y = M_1 + M_2Z_1 + M_3Z_2 + M_4Z_3 + M_5Z_1Z_2 + M_6Z_2Z_3 + M_7Z_1Z_3
\]

The fitness function is constructed by the minimum variance between fitting value and measured value of corn yield as formula (4):

\[
f(x) = \sum_{i=1}^{n} (\hat{y}_i - y_i)^2
\]

Where \(\hat{y}_i\) is the fitting value of corn yield; \(y_i\) is the measured value of corn yield; \(n\) is number
of data groups; $f(x)$ is the objective function.

3. Results
The relationship between irrigation lower limit and yield in different stages is researched on the data of field experiment in 2014, and the results are shown in Table 5. F values in both knee-high stage and tasselling are more than 3.19 in 0.1 tested level. To improve that irrigation lower limit in knee-high stage and tasselling stage has significant impact on yield, and irrigation lower limit in maturity has no significant impact on yield. The results show that the influence of the different irrigation lower limits for each growth stage on corn production: tasselling $>$ knee-high $>$ maturity.

| Treatment X1 | X2 | X3 | Y (kg/hm²) |
|--------------|----|----|------------|
| 1            | -1 | -1 | 14746      |
| 2            | 0  | 0  | 14250      |
| 3            | 1  | 1  | 15190      |
| 4            | -1 | 0  | 14893      |
| 5            | 0  | 1  | 14844      |
| 6            | 1  | -1 | 14943      |
| 7            | -1 | 1  | 15982      |
| 8            | 0  | -1 | 14349      |
| 9            | 1  | 0  | 14943      |
| 10           | /  | /  | 10135      |

A significant difference between the drip irrigation under mulch treatment and control treatment can be seen from Table 6. The relationship of water consumption in drip irrigation groups under mulch is shown as follows: tasselling $>$ knee-high $>$ maturity. The relationship of water consumption in control group is shown as follows: knee-high $>$ tasselling $>$ maturity. Yield of drip irrigation under mulch is increased by 47% compared with control group and water consumption is increased by 63%.

| Treatment | Emergence (mm) | Knee-high (mm) | Tasselling (mm) | Maturity (mm) | Full period (mm) |
|-----------|----------------|----------------|-----------------|---------------|------------------|
| 1         | 16.56          | 189.48         | 232.11          | 29.81         | 467.95           |
| 2         | 18.85          | 180.28         | 226.47          | 32.49         | 458.08           |
| 3         | 14.77          | 191.91         | 280.51          | 39.32         | 526.50           |
| 4         | 15.12          | 193.92         | 251.34          | 39.53         | 499.91           |
| 5         | 13.31          | 193.56         | 242.43          | 41.34         | 490.63           |
| 6         | 21.06          | 187.35         | 235.27          | 19.81         | 463.48           |
| 7         | 13.82          | 186.86         | 250.45          | 34.03         | 485.15           |
| 8         | 16.06          | 184.77         | 244.83          | 16.34         | 462.00           |
| 9         | 17.25          | 191.45         | 246.77          | 11.80         | 467.26           |
| Control   | 24.42          | 147.41         | 103.85          | 18.26         | 293.94           |

The relationships between temperature and height of plant in 2014 and 2015 are shown in Figure 6 and Figure 7. The temperature of twenty days after sowing in 2015 is lower than 2014, and it is one reason which has a part of influence on the final yield of corn in 2015 as emergence in 2015 is later than 2014. Yield and the height of plant in 2015 are generally lower than that in 2014.
Figure 6. The relationship between temperature and plant height of total stages in 2014

Figure 7. The relationship between temperature and plant height of total stages in 2015

It can be seen that the times of rainfall in 2015 are less than 2014 and the dry matter of corn in 2015 decreases by 12.6% than 2014 by comparing Figure 8 and Figure 9. Annual corn yield of common farmland in Changchun city is 10000kg/hm² in 2014, but the annual corn yield in 2015 is only 7000kg/hm², which is reduced by 30% than 2014. Yield of high photosynthetic efficient drip irrigation under mulch in 2015 is decreased by only 10.6% than 2014, and it proves that this method is better to fight against the extreme weather than common farmland.

Figure 8. Rain and dry matter of total stages in 2014
The relationship between irrigation lower limit, amount of nitrogen fertilizer and yield in 2015 is shown in Table 7. Run genetic algorithm till the optimum solution is found. Correlation equation of different nitrogen fertilizer amounts, different irrigation lower limits and yield of corn is measured as follows:

\[ Y = 9070Z_1 + 160Z_2 - 2030Z_3 - 183470Z_1Z_2 - 25890Z_1Z_3 + 2930Z_2Z_3 + 13520 \]  \hspace{1cm} (5)

The root mean square error of the mathematical model obtained by genetic algorithm is 6.624+E005. Correlation coefficient is 0.88 through analyzing the 1-1 figure of genetic mathematical model between measured yield and fitted yield, and it proves that genetic algorithm can obtain a well-defined mathematical model.
4. Conclusion
A new type of corn cultivation, high photosynthetic efficient and drip irrigation under mulch, can get the purpose of increasing production. The results show that the influence of the different irrigation lower limits for each growth stage on corn production: tasselling > knee-high >maturity, and this method is better to fight against the extreme weather than common farmland. Correlation equation of different nitrogen fertilizer amounts, different irrigation lower limits and yield of corn is measured by genetic algorithm, and it proves that genetic algorithm can obtain a well-defined mathematical model. It is suggested that changing conventional cultivation method to high photosynthetic efficient drip irrigation under mulch method by analysis can lay a foundation for increasing yield.

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