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ARTICLE

Assessment of Household Food Security and Its Determinants in Minjar Shenkora and Ada'a *woredas* of Central Ethiopia

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ABSTRACT

Food security issues become one of the critical concerns and top priority areas for Ethiopia. This study analyzed rural households' food security status and its determinants in Minjar Shenkora *woreda* of Amhara Regional State and Ada'a *woreda* of Oromia Regional State. Data were collected from 240 randomly selected rural farm households. The study employed both descriptive statistics and a binary logistic regression model to estimate the status and determinants of households' food security, respectively. The findings indicated that the average dietary energy available for food secured households was 2,860.6 kilo calorie per day while 1,891.7 kilo calorie per day for the insecure group. According to the findings of the binary logit model, factors such as education level, farm size, livestock ownership, cooperatives membership, off-farm income and credit access have positive and significant effects on household food security. While household size has a negative and significant effect on household food security. The results recommend that interventions should target at improving rural financial services and off-farm activities that increase households' income and focusing on those most significant variables when attempting to enhance household food security.

1. Introduction

One of the key challenges in the worldwide development agendas, such as the sustainable development objectives (SDGs), is food security. It is world's greatest challenge to secure physical, social, and economic access to sufficient, safe, and nutritious food for all people at all times for an active and healthy life, in an environmentally sustainable manner [1,2]. This demonstrates its equal importance for both developed and developing countries. The vast majority of those who lack access to food reside in developing nations, including those in Asia, Africa, Latin America, and the Caribbean [3]. However, significant progress has been made in reducing hunger and poverty. Unfortunately, the number of people experiencing food insecurity has been continuously increasing, mostly due to

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an increase in moderate food insecurity. Over 2.37 million individuals worldwide are currently experiencing moderate to severe food insecurity. One third (799 million) of the 2.37 billion people live in Africa, while 11.7% (267 million) live in Latin America and the Caribbean [3].

Ethiopia is one of the African nations that are frequently brought up in relation to the issue of food insecurity. Ensuring food security for today's population and generations to come is one of the greatest challenges of Ethiopia. Ethiopians consume fewer than 2100 kcal per person per day [4]. The fact that nearly one in five Ethiopians needed food assistance during the 2015–2016 drought shows both how widespread food insecurity is and how many people are at risk of developing it. Moreover, about 25% of the population still lives below the officially recognized poverty line, despite attempts to improve food security at the family level [5]. There are 26 million households, or around 20.5 percent, that are estimated to be food insecure [6]. Ethiopians living in rural areas currently rely on ongoing welfare transfer programs in excess of 20 million times [7]. Ethiopia was ranked 108 [8] in the Global Food Security Index and 173 [9] in the Human Development Index.

Several studies have found that Ethiopians have experienced prolonged periods of food insecurity, which can be attributed to a variety of factors [10-13]. Most people's "physical, social, and economic access to sufficient, safe, and nutritious food necessary to meet dietary demands and food choices for leading an active and healthy life" has been hampered by these variables. The causes of food insecurity are categorized into five categories in a detailed account: biophysical shocks or stresses, lack of access to assets for sustaining livelihoods, restrictions on livestock, access-related restrictions like a lack of opportunities, start-up funds, knowledge, and skills, and inappropriate land rights arrangements [13]. Various factors that contribute to household food insecurity in Ethiopia have also been discovered [12,14]. In light of this, the study was mainly focused on assessing rural household food security situation in Ethiopia and determinants of food security. The study offers insight into the nature of food security and its determinants, allowing researchers and policymakers interested in future research and policy implementation to use the model to address food insecurity at the household level.

The findings of this study will add to the existing of literature by identifying the factors of food insecurity in households where *tef* production and consumption are the primary sources of income and subsistence. In order to design potential interventions to address those factors, it is crucial to identify the associated attributes of household food insecurity. This study varies from the majority of other studies in that it considers *tef* as a staple meal and takes into account the significant *tef*-growing regions of Minjar Shenkora and Ada'a *woredas*. This study adds to the limited empirical evidence at the local level by assessing household food insecurity and associated factors in the study areas.

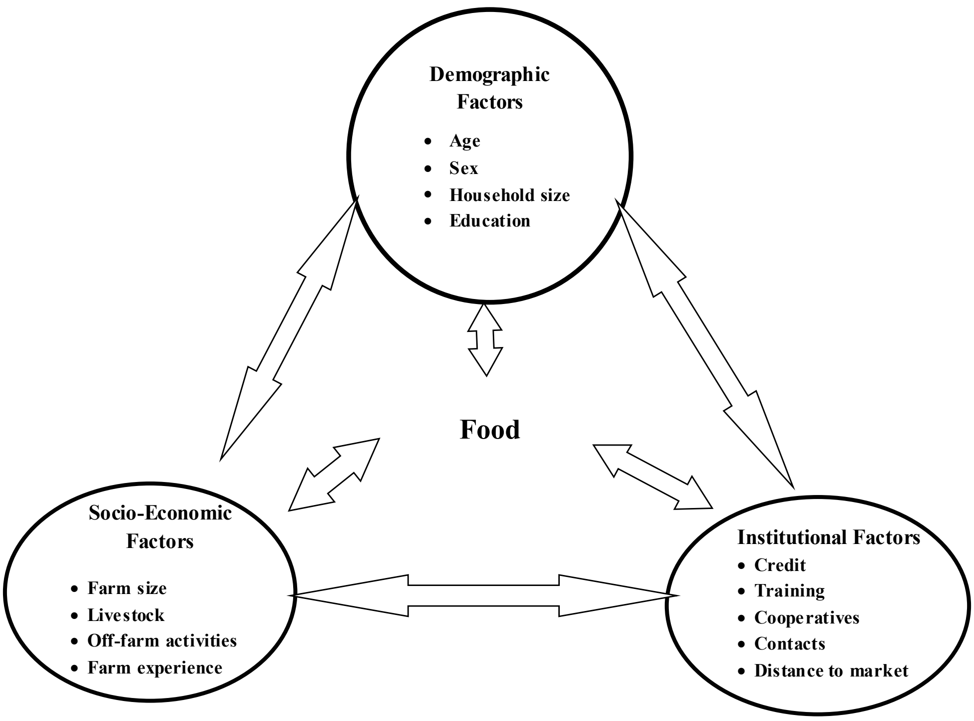

Figure 1. The association between dependent and independent variables

2. Materials and Methods

Description of the study area

The survey was conducted in Minjar Shenkora *woreda* of Amhara Regional State and Ada'a *woreda* of Oromia Regional State of Ethiopia. Minjar Shenkora is one of the *woredas* in the North Shewa Zone of Amhara Regional State of Central Ethiopia. The administrative center of the *woreda* is Arerti. It is located farther to the southern part of North Shewa Zone, and located at about 135 km southeast of the Capital city, Addis Ababa. The *woreda* is composed of a total of 30 *kebeles*, 27 rural *kebeles*, and the rest urban *kebeles*. *Tef*, wheat, sorghum, and maize are among the cereal crops and chickpea and lentil among pulses grown in the *woreda*. Ada'a is one of the *woredas* in East Shewa Zone of Oromia Regional State of Central Ethiopia. The *woreda* administrative town is Bishoftu, which is located 45 km away east of Addis Ababa. Ada'a *woreda* is a mixed farming, crop production, and livestock production area. Crops grown in the *woreda* are *tef*, wheat, barley, maize sorghum, chick pea, ground nut, root crops, and vegetables.

Data source and sampling procedures

The data for this study were obtained from both quantitative and qualitative sources. Quantitative data were collected through a household survey. A multistage sampling procedure was employed to draw sample households in the study areas. In the first stage, two *woredas*, Minjar Shenkora and Ada'a *woreda* were selected based on their *tef* production potential. In the second stage, four kebeles from high and low producing areas were randomly selected. In the third stage, representative households from each sample *kebeles* were determined by using a formula suggested by Yamane [15]. This simplified formula required sample size at 95% confidence level, degree of variability = 0.5, and level of precision = 5%. Finally, based on proportionate random sampling, 240 households were selected on the lottery method from the list obtained from respective *kebeles*.

Methods of data analysis

The study used descriptive statistics (frequency, percentage, mean, standard deviation) and Descriptive statistics (frequency, percentage, mean, standard deviation) on various indicators of food security and their determinants including socio-demographics, resource endowments, institutional services, and markets were computed. Moreover, inferential statistics (such as t-test, and Chi-square test) were used to estimate the food security status in the study areas. The Household Food Balance Model (HFBM) was also used.

The food security status is a binary outcome variable that takes a value of Y = 1 if the household is food secure, 0 otherwise. The binary logit model was used to determine the factors influencing of different explanatory variables on food security situation. The functional form of logit model can be specified as follows where P_i donates the probability of household food secure that is $Y_i = 1$ and $exp^{(Zi)}$ stands for the irrational number to the power of Z_i [16,17]. The model can be written as:

$$P_i = E\left(Y = \frac{1}{X_i}\right) = \frac{1}{1 + e^{-(\beta 0 + \beta 1 X1)}} \quad (1)$$

For the case of explanation, Equation (1) is written as:

$$P_i = \frac{1}{1 + e^{-Zi}} \quad (2)$$

The probability that a given household farmer is decided to food secure properly is expressed as by Equation (2), while the probability of food insecure is expressed by Equation (3)

$$P_i = \frac{1}{1 + e^{Zi}} \quad (3)$$

Variable definition and measurement

Definitions and measurements of the outcome and explanatory variables are presented in Table 1.

Table 1. Definition and measurement of variables used in the analysis

Variables	Definitions and Measurement
SEX	1= if the household head is male and 0 otherwise
AGE	Age of the household head in years
EDUCATION	1= if the household head is literate and 0 otherwise
HH_SIZE	Household size in Adult equivalent
FARM_SIZE	Farm size in hectare
FARM_EXP	Farm experience in years
LIVESTOCK	Livestock ownership in TLU
OFF_FARM	1= if household engaged in off farm activities and 0 otherwise
CREDIT	1= if the household access credit and 0 otherwise
COOPERATIVES	1= if the household member of cooperative and 0 otherwise
CONTACTS	Frequency of DA contacts with farmers
TRAINING	1= if the household access to training and 0 otherwise
DIS_MARKET	Distance to the nearest market in kilometer

3. Results and Discussion

Food availability and dietary energy supply of sample households

The mean difference between food secure and food insecure households was statistically significant at ($p<0.01$). The observation of the range (min= 1,023.8 kcal/ADE/day and max= 7,547.7 kcal/ADE/day) implies that there was a great variation among the farming households so that looking into the conditions of each households was essential.

Descriptive results of hypothesized variables

Table 3 presents a summary of the explanatory variables used in econometric estimation and tests if systematic associations between socio-demographic characteristics and the food security status of the farm households. The results show that the food secure and insecure households have a significant difference in most of the explanatory variables. For example, the mean household size of food secure households (4.1 ADE) was smaller than that of food insecure households (5.0 ADE) showing that their mean difference was statistically significant between the groups at ($p<0.01$). Likewise, the mean livestock possession for food secure households (6.2 TLU) was larger than that of food insecure households (4.9 TLU). Their mean difference in livestock ownership between the two groups was statistically significant at ($p<0.01$).

Moreover, the dummy variables demonstrate that among 90% of households headed by male, 57% of them were food secured whereas about 33% of food insecure groups. Their mean difference was statistically significant between the groups at ($p<0.01$). Similarly, results indicated that 64% of households had no access formal education. Out of this, about 24% of food secured households while 40% of food insecure groups showing that their mean difference was statistically significant between the groups at ($p<0.01$). Besides, among 70.4% of households who are member to agricultural cooperatives, about 48% belongs to food secure and 23% belongs to food insecure. Their mean difference was statistically significant between the groups at $p<0.01$.

Determinants of household food security

Table 4 shows the results of a logistic regression study that shows the association between household food security and its determinants. Out of 13 hypothesized variables, 7 were statistically most significant at less than ($p<0.1$) level of significance. Among these, education level, household size in adult equivalent, membership in agricultural cooperatives, livestock ownership and engaged in off-farm activities were mostly significant at ($p<0.01$). But, it does not mean that the remaining determinant variables had no influence on food security.

Household food security and education are inextricably linked because, especially in subsistence farming, literate farm household heads outperform illiterate counterparts in a variety of ways, yet the importance of indigenous knowledge in achieving food security should not be overlooked [13]. Our result is in line with this study because it showed that education of household head influenced household food security positively (B = 0.290) and significant at ($p<0.01$). The odds ratio in favor of the probability of being food secure increased by a factor of 0.914 with one year increase in the level of education. This indicates that households headed by relatively better educated were more likely to be food secure than those headed by less educated or illiterate ones. This goes in line with some previous studies which showed statistically significant and positive relationship between level of household head education and the probability of being food secure [18-20,11].

The effect of household size on food security was negative (B = –0.712) and statistically most significant at ($p<0.01$). By keeping other factors constant, the odds ratio in favor of being food secure decreased by a factor of 3.491 with an increase in the household size by one member. This indicates that households with larger household size are more likely to be food insecure than their counterparts. The negative association could be due to an increase in the number of family dependency ratio. This means that households having many children and old age groups may lack sufficient manpower, which eventually results in overdependence on limited household resources. This result is consistent with several previous research findings [21,22].

Livestock is a source of income through the sale of livestock and livestock products, as well as a source of supplementary food. Furthermore, livestock can be used as a coping strategy in the event of crop failure or other disasters. Households with greater livestock holdings are shown to be more food secure than those without. Our results also confirmed that the effect of livestock holdings on household food security was positive and statistically most significant at ($p<0.01$). The odds ratio (B = 0.149) in favor of being food secure was increased by a factor of 1.161 with an increase in livestock ownership by one TLU. This goes in line with most previous studies including [18,23].

Farm households who are members in agricultural cooperatives can easily access credit, agricultural inputs, information, and stable market outlets. This implies that households who are members in agricultural cooperatives are shown to be more food secure than those who are not. Results indicated that the effects of membership in agricultural cooperatives ion household food security was positive and statistically most significant at ($p<0.01$). The odds ratio (B = 0.230) in favor of being food secure was increased by a factor of 0.794 with an increase in membership in agricultural cooperatives.

Off-farm activities are important activities through which rural households get additional income to supplement their livelihoods. Households who engaged in off-farm activities are less risk-averse than farmers without sources of off-farm income. Our result showed that the effect of off-farm income on household food security was positive and statistically most significant at ($p<0.01$). The odds ratio (B = 0.438) in favor of being food secure was increased by a factor of 1.039 with an increase in off-farm income by one Ethiopian Birr (ETB).

Table 2. Sample households' dietary energy supply (Kcal/ADE/Day)

Households	Minimum	Maximum	Mean	SD	Sum	Chi-square
Food insecure (n= 89)	1,023.8	2,098.5	1,891.7	272.3	172,140.6	24.387***
Food secure (n= 151)	2,104.7	7,547.7	2,860.6	860.2	423,372.5	
Pooled (N= 240)	**1,023.8**	**7,547.7**	**2,491.2**	**839.7**	**597,603.3**	

Note: *, **, and *** denotes significance level at 10%, 5%, and 1%; NS= not significant
Source: Own calculation based on field survey

Table 3. Summary statistics of explanatory variables by food security status

Variables	Food insecure (n= 89)	Food secure (n= 151)	Pooled (N= 240)	Mean Difference
Continuous Variables				t-test
AGE	45.9 (13.2)	45.2 (12.1)	45.5 (12.5)	0.705
HHSIZE	5.0 (1.9)	4.1 (1.9)	4.5 (1.9)	3.003***
FARM_SIZE	2.4 (1.6)	2.9 (2.0)	2.7 (1.9)	3.457*
LIVESTOCK	4.9 (3.1)	6.2 (4.6)	5.8 (4.2)	10.582***
CONTACT	2.5 (3.2)	3.8 (8.1)	3.3 (6.7)	1.744***
FARM_EXP	15.8 (9.5)	14.6 (10.2)	15.0 (9.9)	0.627
DIS_MARKET	10.7 (6.7)	7.1 (10.7)	10.2 (6.9)	2.355***
Dummy Variables				Chi-square
SEX (male)	32.9	57.1	90.0	2.224***
EDUC (illiterate)	40.4	23.8	64.2	1.375***
COOPERATIVE (yes)	22.9	47.5	70.4	5.044***
OFF_FARM (yes)	6.3	10.0	16.3	1.038*
CREDIT (yes)	19.6	36.7	56.3	4.681**
TRAINING (yes)	25.4	44.6	70.0	3.144*

Note: *, **, and *** denotes significance level at 10%, 5%, and 1%, t-test is estimated as a mean difference between food insecure and food secured
Source: Own calculation based on field survey

Table 4. Results of binary regression model parameters estimating the effects of determinants

Explanatory Variables	B	S.E.	Wald	Sig.	Exp (B)
SEX	–0.741	0.705	1.105	0.293	0.477
AGE	0.030	0.016	3.391	0.266	1.031
EDUCATION	0.290	0.276	10.416***	0.000	0.914
HHSIZE	–0.712	0.156	20.960***	0.004	3.491
FARM_SIZE	0.075	0.127	1.348*	0.055	1.078
FARM_EXP	0.877	0.518	2.874	0.090	2.404
LIVESTOCK	0.149	0.81	3.396***	0.003	1.161
COOPERATIVES	0.230	0.478	8.232***	0.000	0.794
OFF_FARM	0.438	0.211	12.663***	0.000	1.039
CONTACTS	0.342	1.541	2.945	0.059	0.893
CREDIT	0.146	1.461	4.636**	0.046	2.244
TRAINING	0.518	0.477	1.178	0.078	1.678
DIS_MARKET	–0.013	0.031	0.167	0.683	0.987
Constant	–1.848	1.153	0.542	0.462	0.428
Model Prediction Success (%)		Food secure		85.8	
	Food insecure		78.8		
	Overall predicted		82.9		
-2 Log-likelihood ratio for the model		174.452			
H-L model test (df = 8)		14.058 (p= 0.08)			
Nagelkerke R^2		0.63			

Notes: *** p < 0.01, ** p < 0.05, * p < 0.1; Dependent variable: =1 if the household is food secured, 0 otherwise.

4. Conclusions and Suggestion

Food security remains an issue in Ethiopia particularly in the rural households. It is one of the greatest challenges for today's population and generations to come. Hence, this study, therefore, attempted to identify the status and driving factors of household food security in Minjar Shenkora and Ada'a *woredas* of Central Ethiopia. This study indicated that about 64% of sampled households were food secure while the remaining 36% are food insecure. The empirical evidence suggests that food security of rural households is greatly influenced by various factors. There is no one-size-fits-all solution to the challenge of food security. The binary logistic regression model results showed that the household head's education level, household size, livestock ownership, membership in agricultural cooperative, incomes from off-farm activities, credit availability, and farm size all had significant effects on the probability that the household will be food secure. Hence, interventions should target at improving rural financial services, markets and off-farm activities that increase households' income and focusing on those most significant variables when attempting to enhance household food security.

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Conflict of Interest

There is no conflict of interest.

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ARTICLE

Performance Evaluation of Manually Operated Mulch Laying Machine on Different Soil Conditions

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ABSTRACT

A machine with manual operation for mulch-laying machine with a punching arrangement was developed, and its performance was assessed at three different mulch paper thicknesses (15 m, 20 m and 25 m), three different disc angles (35 degrees, 40 degrees, and 45 degrees), three different punch spacings (250 mm, 500 mm, and 1000 mm), and three different forward speeds (1.3 km/h, 1.5 km/h, 1.7 km/h) to investigate their effects on field capacity, effective field efficiency, and punching efficiency. Utilizing randomised block design and response surface methods, the experimental plan for optimization was created. All of the independent variables' combined effects on the dependent variables were found to be statistically significant. The influence of operating speed and mulch paper thickness was found to be the most significant on the dependent variable. The effective field capacity and field efficiency increased from 0.11 ha/h to 0.19 ha/h and 72.04 percent to 89.51 percent, respectively, by increasing mulch paper thickness from 15 µm to 25 µm and operating speed from 1.3 km/h to 1.7 km/h, whereas punching efficiency fell from 85.18 percent to 84.40 percent. Mulch paper of 15 µm and a disc angle value of 40 degrees were optimised from the independent factors that were chosen for optimal soil covering over the laid plastic mulch sheet. Punching efficiency was maximised with performance optimised at 500 mm punch spacing. Additionally, the machine operated more efficiently at 1.5 km/h.

1. Introduction

In India, agriculture and allied sectors contributed 18% of the India's gross domestic product (GDP) in the year 2014-2015 [1,2]. A large proportion of this contribution comes from the horticultural sub-sector.

Konkan region of Maharashtra is specially known as horticultural zone. Vegetable cultivation and floriculture are commercial ventures in Palghar, Thane and Raigad districts. Mulching operation and shade-net houses are

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used for capsicum, cucurbits, water melon, betel vine and other vegetables cultivation. In order to protect the plant and its roots from the impact of high temperature variations, the mulching process entails covering the soil surrounding the plant's root area. The advantages of mulching are to reduce deterioration of soil by controlling the rate of movement of water and its runoff, restrict the rain water flow rate, soil water runoff and avoiding the direct entry of solar radiation.

Manual mulch laying operations are time consuming, labour intensive, costly, tedious and result in improper laying of mulch paper, poor quality of work, tearing of paper during handling and difficulty in covering of mulch paper. The popularity of using mulch paper for growing vegetables and fruit crops is increasing day by day in Konkan region but application of mulch paper in the field with manual method limits its effective use [2]. Also, different tractor operated mulch paper laying equipment were developed and are commercially available. But, in spite of having higher efficiency, they are unsuitable to use in Konkan region due to, marginal lands, undulated slope of land and poor economical condition, Considering all these points it became necessary to develop manual operated mulch laying machine suitable for small scale farmers of Konkan region [5].

2. Material and Methods

2.1 Experimental Setup

The field was prepared with the help of tractor drawn rotavator and land leveler was used to level the field before mulching operation. The constructional components of the developed machine included main frame, bund former, mulch holder, press wheels, covering discs, punching wheels and handle. The overall weight of the machine was about 60 kg. The components were fabricated using galvanized iron and mild steel. The overall dimensions of the machine were 2000 × 1500 × 1000 mm. The developed mulch laying machine and its components are shown in Figure 1. The bund former mounted on main frame was developed for preparation of soil beds. The height of the bund former was adjusted as the field condition and the width of bed could be adjusted as per crop requirement. The mulch holder was mounted behind the bund former to lay the plastic mulch paper which was raised at a height of about 4 inches. The use of pneumatic press wheels was done to compress the laid mulch paper on the prepared bed. Two discs inclined at a variable angle of 35 degree, 40 degree and 45 degrees were attached at the end of main frame to cover the edges of mulch paper. The width of mulch paper used was 1200 mm. Four punching cups of variable spacing (i.e. 250 mm, 500 mm and 1000 mm) were mounted on the periphery of the wheels. The machine was manually pulled by two persons.

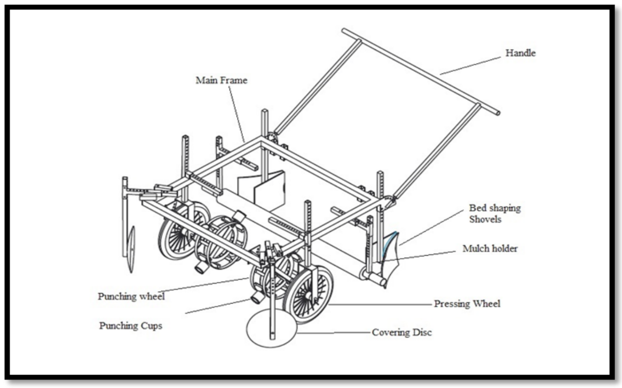

Figure 1. Different components of developed manually operated mulch laying machine response surface method

Four independent variable of disc angle (35 degree, 40 degree and 45 degree), thickness of mulch paper (15 µm, 20 µm and 25 µm), speed of operation (1.3 km/h, 1.5 km/h and 1.7 km/h) and punch spacing (250 mm, 500 mm and 1000 mm) were considered for optimization. The experimental plan for optimization included three dependent variables, viz. field efficiency field capacity and punching efficiency. Thus, response surface methodology (RSM) with randomized block experimental design (RBD) was employed to fit a second order quadratic equation on the experimental data.

The independent variables were implemented at three levels in RBD-type experimental design and finally, 81 experiments were conducted as shown in Table 1. The experiments were carried out in a continuous order. The three replications were performed. The design expert software (Version 11) was used for simultaneous optimization of the multiple responses.

2.2 Evaluation Procedure

For calculating the effective field capacity the data sheet were prepared for recording the time loss during turning, adjusting punching wheels and adjustment in field and actual performance of machine was also recorded [3].

$$EFC(ha/h) = \frac{A}{T_p + T_t} \tag{1}$$

where,

EFC = Effective field capacity, ha/h

A = Area covered, ha

Tp = Productive time, h

Tt = Non-productive time, h

Table 1. Design Experiment Using Randomized Block Design (RBD)

Experiment	Thickness of mulch paper	Disc angle	Punch spacing	Speed of operation
1	15	35	250	1.3
2	15	35	250	1.5
3	15	35	250	1.7
4	15	35	500	1.3
5	15	35	500	1.5
6	15	35	500	1.7
7	15	35	1000	1.3
8	15	35	1000	1.5
9	15	35	1000	1.7
10	15	40	250	1.3
11	15	40	250	1.5
12	15	40	250	1.7
13	15	40	500	1.3
14	15	40	500	1.5
15	15	40	500	1.7
16	15	40	1000	1.3
17	15	40	1000	1.5
18	15	40	1000	1.7
19	15	45	250	1.3
20	15	45	250	1.5
21	15	45	250	1.7
22	15	45	500	1.3
23	15	45	500	1.5
24	15	45	500	1.7
25	15	45	1000	1.3
26	15	45	1000	1.5
27	15	45	1000	1.7
28	20	35	250	1.3
29	20	35	250	1.5
30	20	35	250	1.7
31	20	35	500	1.3
32	20	35	500	1.5
33	20	35	500	1.7
34	20	35	1000	1.3
35	20	35	1000	1.5
36	20	35	1000	1.7
37	20	40	250	1.3
38	20	40	250	1.5
39	20	40	250	1.7
40	20	40	500	1.3
41	20	40	500	1.5
42	20	40	500	1.7
43	20	40	1000	1.3
44	20	40	1000	1.5
45	20	40	1000	1.7

Table 1 continued

Experiment	Thickness of mulch paper	Disc angle	Punch spacing	Speed of operation
46	20	45	250	1.3
47	20	45	250	1.5
48	20	45	250	1.7
49	20	45	500	1.3
50	20	45	500	1.5
51	20	45	500	1.7
52	20	45	1000	1.3
53	20	45	1000	1.5
54	20	45	1000	1.7
55	25	35	250	1.3
56	25	35	250	1.5
57	25	35	250	1.7
58	25	35	500	1.3
59	25	35	500	1.5
60	25	35	500	1.7
61	25	35	1000	1.3
62	25	35	1000	1.5
63	25	35	1000	1.7
64	25	40	250	1.3
65	25	40	250	1.5
66	25	40	250	1.7
67	25	40	500	1.3
68	25	40	500	1.5
69	25	40	500	1.7
70	25	40	1000	1.3
71	25	40	1000	1.5
72	25	40	1000	1.7
73	25	45	250	1.3
74	25	45	250	1.5
75	25	45	250	1.7
76	25	45	500	1.3
77	25	45	500	1.5
78	25	45	500	1.7
79	25	45	1000	1.3
80	25	45	1000	1.5
81	25	45	1000	1.7

Field efficiency was calculated by the ratio of effective field capacity to theoretical field capacity and expressed in percentage.

$$\text{Field Efficiency, per cent} = \frac{\text{Effective Field Capacity}}{\text{Theoretical Field Capacity}} \times 100 \quad (2)$$

Punching efficiency was calculated by the ratio of actual punches to the calculated punches on mulch paper and expressed in percentage.

$$\text{Punching Efficiency, per cent} = \frac{\text{Actual punches}}{\text{Calculated punches}} \times 100 \quad (3)$$

3. Results and Discussion

The effect of selected independent variables, individually and in combination are discussed in sections 1 to 8.

3.1 Effect of Mulch Paper Thickness on Field Capacity, Field Efficiency and Punching Efficiency

It was observed from Table 2 that, effective field capacity and field efficiency increased with increase in mulch paper thickness. It might be because reduction in mulch paper thickness resulted in increased paper weight ultimately adding extra load on the machine frame. Conversely, the punching efficiency decreased with increase in thickness of mulch paper which would have been due to easy penetration of punching cups on the minimum thickness mulch paper.

Table 2. Mean value table for effect of thickness of mulch paper on field capacity, field efficiency and punching efficiency

Thickness of paper (μm)	Field capacity (ha/h)	Field efficiency (%)	Punching efficiency (%)
15	0.142	77.43	88.20
20	0.146	79.72	86.85
25	0.149	80.73	78.55

3.2 Effect of Disc Angles on Field Capacity, Field Efficiency and Punching Efficiency

The effect of disc angles at 35, 40 and 45 degree on effective field capacity, field efficiency and punching efficiency calculated separately concluded that field capacity and field efficiency decreased with an increase in disc angle. It might be because 45 degree angle of soil covering disc carried greater volume of soil than 35 degree disc angle. Also, there was no considerable effect on the punching efficiency with increase in disc angle which might be due to the consideration that changing of the disc angle did not directly or indirectly affected the performance of punching cups which can be seen in Table 3.

Table 3. Mean value table for effect of disc angles on field capacity, field efficiency and punching efficiency

Disc angles (degree)	Field capacity (ha/h)	Field efficiency (%)	Punching efficiency (%)
35	0.151	82.29	84.19
40	0.148	80.98	84.78
45	0.141	77.19	84.62

3.3 Effect of Punch Spacing on Field Capacity, Field Efficiency and Punching Efficiency

The results as shown in Table 4 concluded that effective field capacity, field efficiency and punching efficiency increased with increased punch spacing. It might be due to the observation that, single cup mounted on punching wheel rotated freely on the laid mulch bed producing punch spacing of 1000 mm without any disturbance in making punch holes.

Table 4. Mean value table for effect of punch spacing on field capacity, field efficiency and punching efficiency

Punch spacing (mm)	Field capacity (ha/h)	Field efficiency (%)	Punching efficiency (%)
250	0.138	75.84	80.09
500	0.145	79.56	84.48
1000	0.150	81.96	85.8

3.4 Effect of Operational Speed on Field Capacity, Field Efficiency and Punching Efficiency

It was observed that effective field capacity and field efficiency were increased with increase in speed of operation. It might be because when machine operated at maximum speed, the area covered per unit time was maximum. But, punching efficiency varied with increased speed of operation as shown in Table 5.

Table 5. Mean value table for effect speed of operation on field capacity, field efficiency and punching efficiency

Speed of Operation (km/h)	Field capacity (ha/h)	Field efficiency (%)	Punching efficiency (%)
1.3	0.11	72.04	85.18
1.5	0.15	80.00	84.01
1.7	0.19	89.51	84.40

3.5 The Analysis of Variance Showing Effect of Selected Independent Parameters on Dependent Parameters

The statistical analysis of the data was carried out to study the significance of selected independent parameters on dependent parameters and obtained ANOVA table presented in Table 6.

Analysis of variance (ANOVA) for the suggested model was presented in Table 6. As it was observed that the replications "Mean Square Value" of field capacity, field efficiency and punching efficiency was 0.00029, 84.97 and 12.88, respectively which implies that the model were significant. The value of "p-value probability" less than 0.01 indicated that the model terms were significant at 1 per cent level of significance. It may be because of uncontrollable variations such as weather conditions, soil conditions etc. Also, the effect may be due to the handling conditions of the machine by the labour at the time of operations.

It was observed from the Table 6, the selected individual parameters for the experiment, viz. thickness of mulch paper, disc angle, punch spacing and speed of operation were observed to be significant at 1 per cent level of significance. Which shows that the selected parameters were effectively affect on the field capacity and field efficiency but the disc angle does not have the significant effect on punching efficiency.

The combination of thickness of mulch paper and disc angle shows the significant effect on field capacity and field efficiency as because as the thickness of mulch paper were reduced the length and weight of the paper were increased which implies the extra additional load on machine frame also as the disc were not provided with any anti functional accessories such as bearing, it pulls the soil like scraper and covers the soil over the edges of the laid mulch paper which directly affect on the performance of the machine. It also shows the combine effect of thickness of mulch paper and disc angle has the non significant effect on punching efficiency, it may be because as an arrangement of the punching cups provided on the punching wheel which do not have any direct link with soil covering disc. Hence, the effect of changing of soil covering disc angle do not directly or indirectly affect on the performance of punching cups.

The combined effect of thickness of mulch paper and the punch spacing shows the significant effect at the 5 per cent level of significance, it may be due to the increased thickness of mulch paper requires the more pressure by the punching cups for making the holes, which directly affect on the pulling force of machine, ultimately the field capacity and field efficiency of machine get affected. It also shows the combined effect of thickness of mulch paper and the punch spacing has been observed as significant at 1 per cent level of significance on punching efficiency. This may be because as the lesser thickness, punching where effectively carried out on the laid mulch paper, as the thickness increases it directly affects the punching operations [4]. Hence, the effect of the combination of both were observed to be significant.

Table 6. Analysis of variance showing effect of selected independent parameters on dependent parameters

Source	Df	Type I SS			Mean Square		
		EFC (ha/h)	**FE (per cent)**	**PE (per cent)**	**EFC (ha/h)**	**FE (per cent)**	**PE (per cent)**
Rep	2	0.00058	169.94	25.78	0.0003**	84.97**	12.88**
Thickness of mulch	2	0.00308	986.50	4422.33	0.0016**	493.2**	2211.1*
Disc Angle	2	0.00093	242.31	14.98	0.0004**	121.15**	7.48 NS
Punch Spacing	2	0.00034	124.52	357.66	0.0001**	62.26**	178.8**
Speed of operation	2	0.20018	11355.47	57.01	0.1000**	5677.7**	28.50**
Thick×D.Angle	4	0.00022	75.28	59.72	0.0006**	18.82**	14.92**
Thick×Spacing	4	0.00016	56.49	117.26	0.00004*	14.12*	29.31**
Thick×Speed	4	0.00031	134.25	63.44	0.00008**	33.56**	15.85**
D.Angle×Spacing	4	0.00028	105.18	80.65	0.00007**	26.29**	20.16**
D.Angle×Speed	4	0.00065	158.09	15.13	0.00016**	39.52**	3.78*
Spacing×Speed	4	0.00026	94.33	95.74	0.00007**	23.58**	23.93**
Thick×D.Angl×Spacing	8	0.00031	105.22	36.93	0.00004**	13.15**	4.61 NS
Thick×D.Angle×Speed	8	0.00020	66.90	80.86	0.00002*	8.36*	10.10**
Thick×Spacing×Speed	8	0.00042	143.48	168.68	0.00005**	17.93**	21.08**
D.Angl×Spacing×Speed	8	0.00080	288.12	94.42	0.0001**	36.01**	11.80**
Thick×D.An×Spacing×Speed	16	0.00038	139.54	181.64	0.00003*	8.72**	11.35**

"**" Highly significant at 1% level; "*" Significant at 5% level; "*NS*" Non-significant.

The combined effect of the thickness of mulch paper with speed shows the significant effect at 5 per cent level of significance on field capacity and field efficiency and also shows the significant effect at 1 per cent level of significance on punching efficiency, it may be due to the operating speed of machine which may be fluctuated due to weight of mulch paper and the soil conditions which implies the resistive force on the bed forming shovels. Therefore, the combined effect of these two parameters directly affects on the field capacity, field efficiency and punching efficiency of machine [6,7].

The Table 6 shows the highly significant effect of disc angle and punch spacing at 1 per cent level of significance on field capacity and field efficiency and also at 1 per cent level of significance on punching efficiency, it may be because of as the disc angle increases the required pulling force were increased due to which the rotating speed of the punching wheel reduces which requires the more efforts to press the hole on the mulch paper and also it increases the holding time of punches pressing holes on laid mulch. The resultant combined effect of these two parameters directly affects the field capacity, field efficiency and punching efficiency of machine, respectively.

The combine effect of disc angle and speed of operations were seen to be significant at 1 per cent level of significance it may be because as increased angle of disc carries the more volume of soil for covering the edges of laid mulch which implies more pulling force due to which the speed of operation decreases and as a combined effect of both the field capacity and field efficiency of the machine get decreases. It also shows the combine effect of disc angle and speed of operations were seen to be significant at 1 per cent level of significance it may be because as a combined effect of both the punching efficiency of the machine get increases as punch resting time increases due to reduction in speed of operation [8].

It was perceived from the Table 6 that the combine effect of the punch spacing and speed of operation has the significant effect at 5 per cent level of significance. It may be because as the punch spacing increased the contact time of punching cups were reduced and the machine moves speedily on the bed due to which more area were covered with less duration of time. With the combined effect of both, the field capacity and field efficiency of the machine was increased. It was also perceived that the combine effect of the punch spacing and speed of operation has the significant effect at 1 per cent level of significance. It may be because as the speed of machine reduced the contact time of punching cups were increased on the bed due to which the punch formation where more accurate and increases the punching efficiency of machine. Hence, as a result combined effect of both the punching efficiency of machine shows the significant effect on machine performance.

Table 6 shows that the combined effect of three and four parameters were highly significant, which directly affects the performance parameters of the machine viz. field capacity, field efficiency and punching efficiency. This was observed because of the individual parameters significantly affects in the selected combined parameters as such effect of the selected individual variables do not override by the effect of other variables.

3.6 The Effect of Selected Independent Parameters on Field Capacity and Field Efficiency

The effect of three sets of mulch paper thickness, disc angle, punch spacing viz., 250, and speed of operation on field capacity and field efficiency were studied. The graphical representations of the results were shown in Figure 2.

Figure 2a represents the effect of thickness of mulch paper and disc angle on the field efficiency. It was perceived from the figure, that the field capacity and field efficiency was increases with increased thickness of mulch paper from 15 μm to 25 μm. The highest field capacity and field efficiency was observed as 0.15 ha/h and 82 per cent at the 25 μm thickness of mulch paper and at 35 degree disc angle. Similarly, the field capacity and field efficiency decreasing with increased disc angle from 35 degree to 45 degree. The highest field capacity and field efficiency was observed at 35 degree disc angle.

The effect of thickness of mulch and punch spacing on field capacity and field efficiency was shown in Figure 2b. It was observed that the field capacity and field efficiency were increased with increased punch spacing from 250 mm to 1000 mm. The highest field capacity and field efficiency was found 0.15 ha/h and 84 per cent at 1000 mm punch spacing.

Figure 2c presents the effect of thickness of mulch and speed of operation on field capacity and field efficiency. It was observed that the field capacity and field efficiency was increasing with increasing speed of operation from 1.3 km/h to 1.7 km/h. The maximum field capacity and field efficiency was found as 0.185 ha/h and 90 per cent at 1.7 km/h operating speed of machine.

The effect of disc angle and punch spacing on field capacity and field efficiency was presented in Figure 2d. It can be seen that, the field capacity and field efficiency were decreasing with increased disc angle. The maximum field capacity and field efficiency was observed as 0.15 ha/h and 79 percent at the 35 degree disc angle. Similarly, the field capacity and field efficiency was increased with increase in punch spacing from 250 mm to

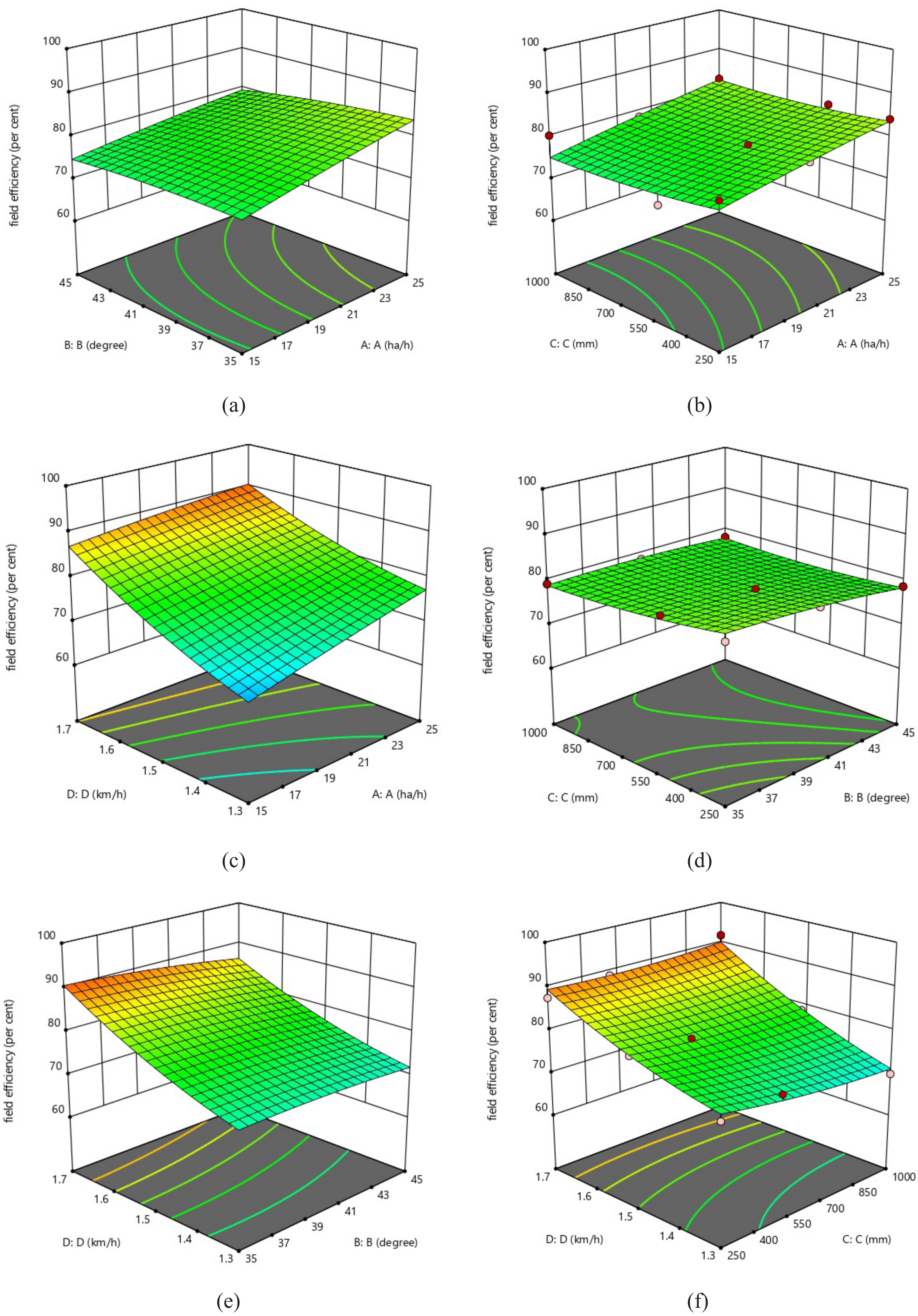

Figure 2. Effect of (a) thickness of mulch and disc angle, (b) thickness of mulch and punch spacing, (c) thickness of mulch and speed of operation, (d) disc angle and punch spacing, (e) disc angle and speed of operation and (f) punch spacing and speed of operation, on field capacity and field efficiency

1000 mm. The highest field capacity and field efficiency was observed as 0.145 ha/h and 79 per cent at the 1000 mm punch spacing.

In Figure 2e, it can be seen that, the field capacity and field efficiency was increasing with increase the speed of operation from 1.3 km/h to 1.7 km/h. the highest field capacity and field efficiency was found that is 0.19 ha/h and 90 per cent at the speed of 1.7 km/h. Similarly, for the disc angle it was observed that the field capacity and field efficiency decreasing with the increased disc angle from 35 degree to 45 degree. The highest field capacity and field efficiency was found at 35 degree disc angle.

Figure 2f presents the effect of punch spacing and speed of operation on field capacity and field efficiency. It was noted that the field capacity and field efficiency were increasing with increase punch spacing from 250 mm to 1000 mm. The maximum field capacity and field efficiency was observed as 0.18 ha/h and 91 per cent at 1000 mm punch spacing at 1.7 km/h speed of operation. Equivalently the field capacity and field efficiency were increase with increasing speed of operation from 1.3 km/h to 1.7 km/h.

3.7 The Effect of Selected Independent Parameters on Effective Punching Efficiency

The effect of three different settings of mulch paper thickness, disc angle, punch spacing and speed of operation on punching efficiency was studied. The results were presented graphically in Figure 3.

Figure 3a shows the effect of thickness of mulch and disc angle on the punching efficiency. It was observed that punching efficiency decreases with increased thickness of mulch sheet from 15 µm to 25 µm. The highest punching efficiency was observed as 87.5 per cent at 15 µm thickness of mulch paper. Similarly, the punching efficiency was observed to be increased with disc angle from 35 degree to 45 degree.

The effect of thickness of mulch and punch spacing on punching efficiency was shown in Figure 3b. It was found that the punching efficiency was increasing with increased punch spacing from 250 mm to 1000 mm. The highest punching efficiency was observed as 89 per cent at 1000 mm punch spacing and at 15 µm thickness of mulch paper.

Figure 3c represents the effect of thickness of mulch paper and speed of operation on punching efficiency. It was perceived that the punching efficiency were decreasing with increased speed of operation from 1.3 km/h to 1.7 km/h. The maximum punching efficiency was observed above 89 per cent at 1.3 km/h speed of operation. Similarly, it was decreasing with increased thickness of mulch paper from 15 µm to 25 µm.

The effect of disc angle and punch spacing on punching efficiency were presented Figure 3d. It was observed that, the punching efficiency was increasing with increased the punch spacing from 250 mm to 1000 mm. The maximum punching efficiency was found as 87 per cent at 1000 mm punch spacing. Similarly, the punching efficiency was found decreased with increased disc angle from 35 degree to 45 degree.

Figure 3e shows the effect of disc angle and speed of operation on punching efficiency. It was observed that, the punching efficiency was decreasing with increased speed of operation from 1.3 km/h to 1.7 km/h. The highest field efficiency was found as 85 per cent at the speed of 1.7 km/h. Similarly, it was seen that the punching efficiency was decreasing with the increased disc angle from 35 degree to 45 degree.

The effect of punch spacing and speed of operation on punching efficiency was presented in Figure 3f. It had been seen that the punching efficiency was increasing with increased punch spacing from 250 mm to 1000 mm. The maximum punching efficiency was recorded as 90 per cent at 1000 mm punch spacing. Equivalently, the punching efficiency was decreased with increased speed of operation from 1.3 km/h to 1.7 km/h.

3.8 Optimization of Selected Independent Parameters of Developed Mulch Laying Machine

For optimizing the values of selected independent parameters, numerical multi-response optimizing technique was used through the Design expert 11.0 of the Stat-EASE Software (Stat ease in Mineapolis, USA, Trial Version).

The outcome shows that the machine performs better at 17.55 µm size of mulch paper as the mulch paper thickness were selected as 15 µm, 20 µm and 25 µm size [9]. As per the availability of 15 µm sheet was selected as the optimize value of paper mulch thickness.

The range of disc angle for the experiment has been selected as 35 degree, 40 degree and 45 degree where the performance were optimized at 40 degree disc angle for effective coverage of soil over the laid plastic mulch sheet.

The punch spacing was selected for the experiment value as 250 mm, 500 mm and 1000 mm respectively; it was observed that at 500 mm punch spacing the field capacity, field efficiency and punching efficiency were increased.

The speed of operation was selected for the experiment value as 1.3 km/h, 1.5 km/h and 1.7 km/h respectively, it was observed that at 1.7 km/h the effective field capacity and field efficiency were increased but the punching efficiency was reduced. So as per the optimized outcome of the data the speed of operation has been selected as 1.5 km/h where the machine performs better on all the selected dependent parameters.

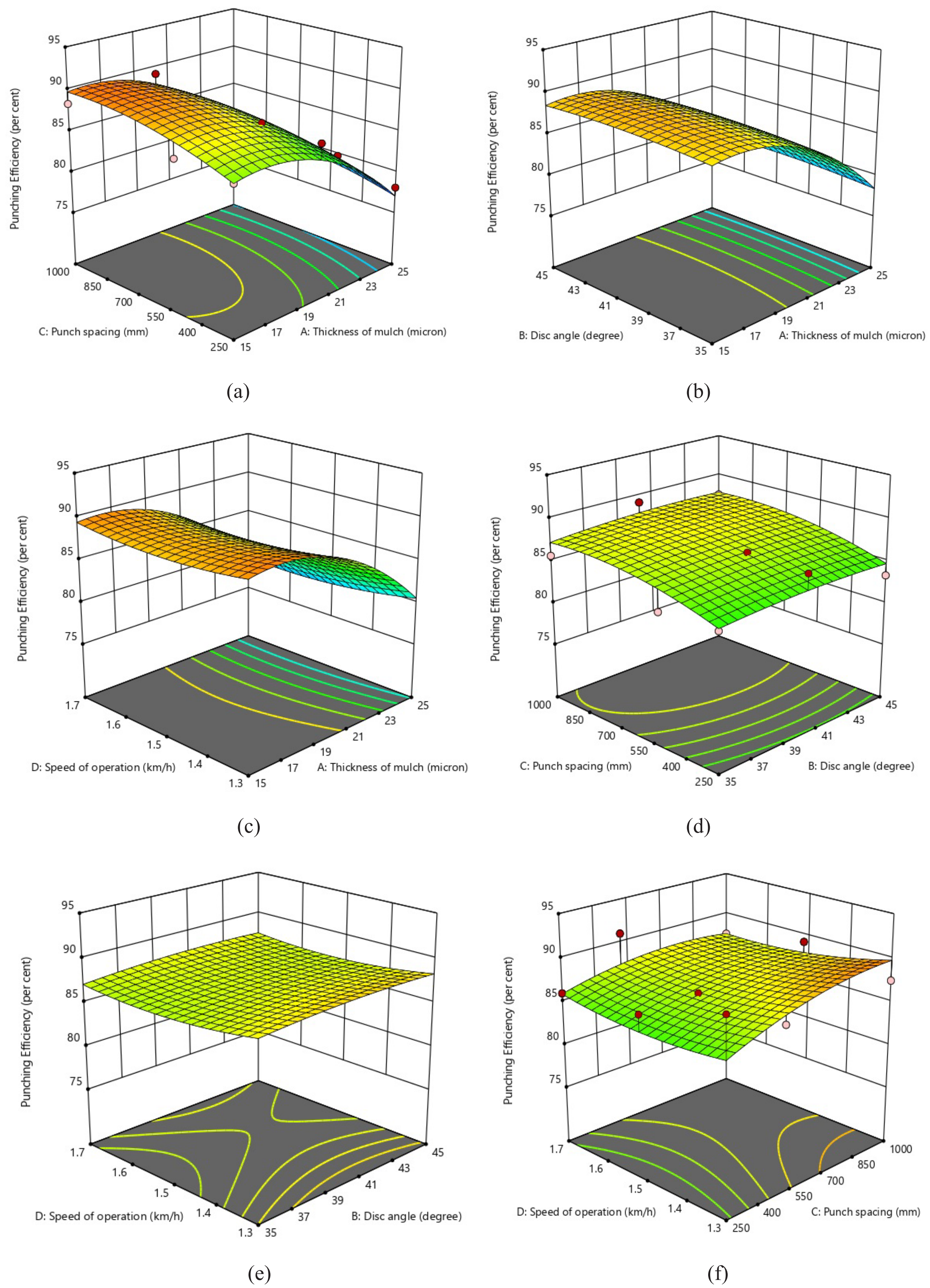

Figure 3. Effect of (a) thickness of mulch and disc angle, (b) thickness of mulch and punch spacing, (c) thickness of mulch and speed of operation, (d) disc angle and punch spacing, (e) disc angle and speed of operation and (f) punch spacing and speed of operation, on punching efficiency

The desired goal for each independent parameters and responses were shown in Table 7. The software generated optimum conditions of independent variables with the predicted values of response was shown in Table 7.

Table 7. Solution generated by the software for manually operated mulch laying machine

Thickness 0f mulch paper µm	Disc angle Degree	Punch spacing mm	Speed of operation km/h	Field capacity ha/h	Field efficiency Per cent	Punching efficiency Per cent
17.16	40.36	444.01	1.55	0.153	80.96	88.55

4. Conclusions

Thickness of mulch paper, disc angles, punch spacing and speed of operation played an important role in mulch laying and punching operation and had significant effect on effective field capacity, field efficiency and punching efficiency. Effective field capacity and field efficiency increases with increase in the thickness of mulch paper, speed of operation and punch spacing but decrease with increase disc angle. Punching efficiency increases with increase in the forward speed and punch spacing, and the effect of thickness of mulch paper was observed the punching efficiency was decrease with increase thickness of mulch paper. Disc angle had no significant effect on punching efficiency. The obtained optimized parameters were set on machine for better performance of selected independent parameters such as 15 µm mulch thickness of mulch, 40 degree angle of soil covering disc for effective coverage of mulch paper, 500 mm punch spacing and 1.5 km/h speed.

Conflict of Interest

There is no conflict of interest.

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ARTICLE

Culture Media Options for Growth and Morphological Characterisation of *Cercospora coffeicola* Affecting Coffee in Zimbabwe

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ABSTRACT

Cercospora leaf spot is fast turning into a critically important disease in Zimbabwe. The disease is caused by *Cercospora coffeicola* which significantly reduces productivity and quality of coffee. Disturbingly, optimum sporulation of *Cercospora coffeicola* in culture remains a limiting factor for microbial analysis and quantitative studies of *Cercospora* leaf spot. Faced with this challenge, an in-vitro study was conducted at Coffee Research Institute, Manicaland, Zimbabwe to examine growth of *Cercospora coffeicola* in different nutrient media and to determine the best media for *Cercospora coffeicola* analysis. Six nutrient media were assessed (corn meal agar, oat meal agar, Czapek Dox agar, malt extract agar, yeast extract agar and potato dextrose agar) for the growth of *Cercospora coffeicola*. The laboratory-based experiment was duplicated, laid out in a Completely Randomized Design, replicated three times and based on *Cercospora coffeicola* nutrient inoculation. Data were collected on radial growth, colour and texture of mycelium at 3 and 6 days after inoculation. There were significant differences ($p < 0.05$) in the growth of *Cercospora coffeicola* in media after 3 and 6 days. Malt extract agar had the greatest radial growth (34 mm and 32 mm) of *Cercospora coffeicola* for trials 1 and 2 respectively, whilst the least growth was in the oat meal agar (14.2 mm and 15.7 mm) for trials 1 and 2 respectively. There were variations in colour and texture of mycelium with malt extract agar, potato dextrose agar and oat meal agar associated with darker colours and rough texture while smooth white mycelia were found in corn meal agar. After considering all nutrient media, malt extract agar was found to be the best media for the growth of *Cercospora coffeicola* in-vitro. On the basis of our findings, the authors recommend the use of malt extract agar as the primary media for identification and characterisation of *Cercospora coffeicola*.

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1. Introduction

Coffee (*Coffea arabica*) is currently one of the best incomes generating socio economic crops across the world for both the smallholder and large-scale commercial farmers. It is one of the most traded crop in the world and the most valuable primary agricultural product in international trade [1,2]. The production of coffee has significant positive reflection on economic growth of many developing and least developed countries in Sub-Saharan Africa, South East Asia, Central and Southern America [3]. It is estimated that there are about three billion coffee trees supplying the needs of the coffee industry worldwide [4,5]. Accordingly, the production of the crop has improved livelihoods of many smallholder farmers and farm workers who solely rely on the valuable commodity for their livelihoods. In addition, the crop due to its perennial nature is very important in climate change mitigation through the provision of carbon sinks across many agricultural landscapes [6]. It is also important in soil erosion management, offering environmental buffering capacity and general ecosystem services [7]. Zimbabwe exports well over 95% of its total production [8], which contributes significantly to the country's total gross domestic product (GDP).

Studies have demonstrated that production challenges in the coffee sector are increasingly becoming more pronounced, extended and severe because of climate change and variability [9,10]. Frequencies of droughts, floods, winds, and disease incidences have negatively impacted on coffee production hence threatening to wipe away the valuable source of livelihoods for many beneficiaries [11,12]. Notably, climate change has increased incidences and severity of pests and diseases, in addition to water stresses, nutrition limitations accelerated by low technology adoption to cope with the challenges.

Although Coffee Leaf Rust (*Hemileia vastatrix*) and Coffee Bark Disease (*Fusarium lateritium*) are among the major constrains to Coffee production in Zimbabwe, *Cercospora* leaf spot caused by *Cercospora coffeicola (C. Coffeicola)*have significantly contributed to reduced coffee yields in Zimbabwe [13]. The *Cercospora* leaf spot disease is one of the oldest and was first reported in 1881 in Jamaica. The disease affects coffee plant growth, cherry yield and also bean quality [14,15].

The symptoms on leaves are circular spots with grey, or white centres and lesions on berries and leaves which are initially brown in colour, sunken, oval in shape, with ashy centres [14,39,15]. *Cercospora* leaf spot and Berry blotch are also referred to as two phases of the same disease. Damage to leaves will lead to defoliation, reduced photosynthetic leaf area and loss of plant vigour [16]. Stressful environment predisposes the coffee trees to attack by *C. Coffeicola* [17]. The bean quality is spoiled by a discolouration symptom which deteriorates the quality of the bean. Under field conditions, Cercospora leaf spot is managed by routine copper based fungicide sprays; a contact fungicide which requires routine sprays which may lead to copper toxicity [18-20]. Several management tactics have been employed to manage the disease which include growing coffee under shade, fertilisation of coffee [21], green manuring in combination with urea treatment [22], were also found to be important in reducing the effects of the disease.

Historically, *Cercospora* of coffee has been considered a minor disease owing to its sporadic nature, confinement to nurseries and low severity ratings recorded in coffee plantations. The occurrence of this disease has also been associated with low management practices such as poor nutrition, water stress and high pest infestation levels [21]. However, in recent years, the incidences and severity of the disease have increased dramatically in all the coffee production zones, mainly in the eastern parts of Zimbabwe [23]. The disease is becoming even more severe with climate change; warm humid summers and the perennial nature of coffee, which can keep inoculum in the field for more than 30 years as a monoculture. Significant losses have been observed within the smallholder communities of Zimbabwe due to the disease [23]. According to Bernardo [24], significant damages caused by *Cercospora* of coffee can be reflected in losses ranging from 15% to 30% in plantations, implying the devastating nature of the pathogen.

Since the disease is assuming importance, the need for early and proper identification is key to avoid significant economic losses. The identification of the pathogen is at times confounded with nutrient deficiency and or water stress [21]. This is also happening because there are no developed ready standards for rapid *Cercospora* identification under laboratory conditions. Limited information is available concerning the biology of the pathogen. It is therefore very important to understand the behaviour of the pathogen under laboratory conditions for proper and early diagnosis.

Conventional pathogen culturing methods have been used for a long period and are regarded as the gold standard procedures in pathogen identification due to their simplicity, low cost, efficiency, sensitivity and reliability over a range of applications with no need for high throughput equipment [25]. This makes them an important step for detection and enumeration of pathogens for various phenotypic and genotypic predictions and analysis. The methods utilize selective media using traditional methodologies under aseptic techniques [26].

There are no specific protocols and suitable media documented for laboratory identification of the *C. coffeicola* on synthetic media. This is the first study which evaluated the response of *C. coffeicola* under laboratory conditions. Potato Dextrose agar has been used to culture *Cercospora* of coffee under laboratory conditions. However, slow mycelia growth has generally compromised the epidemiology process. In addition, difficulty in isolation, obtaining abundant sporulation in the culturing of many species of *Cercospora* remains a limiting factor for quantitative studies of these diseases [27]. It is therefore important to develop standard identification protocols for the pathogen, which will enhance the understanding of its etiology, biology and management options. The study therefore seeks to determine the most suitable media that enhance *Cercospora* mycelia growth under laboratory conditions.

2. Materials and Methods

2.1 Study Sites

The study was carried out at Coffee Research Institute (CoRI), Chipinge, Zimbabwe (latitude 20°12' south and longitude 32°37' east at an altitude of 1100 m above sea level) in the Plant Pathology laboratory. The mean maximum temperature is 20 °C and mean minimum temperature is 14 °C.

2.2 Experimental Design

Two laboratory experiments were laid out in a Completely Randomised Design (CRD) with six media as treatments. The six media treatments were: (i) Corn meal agar (CMA), (ii) Oat meal agar (OMA), (iii) Czapek Dox agar (CDA), (iv) Malt extract agar (MEA), (v) Yeast extract agar (YEA) and (vi) Potato dextrose agar (PDA) which was the standard. The treatments were replicated three (3) times, with three (3) Petri dishes used as a single plot per treatment.

2.3 Culture Media Preparation

In the preparation of the different culture media, the following procedures were followed.

2.3.1 Oatmeal Agar

Seventy-two grams (72 g) of oatmeal agar was measured and suspended in 1000 mL distilled water. The mixture was heated and stirred until the agar was evenly distributed in the distilled water and then autoclaved at 121 °C for 15 minutes.

2.3.2 Cornmeal Agar

Seventeen grams (17 g) of cornmeal agar powder was suspended in 1000 mL of distilled water. The medium was heated and stirred to dissolve the powder completely. Then, the medium was autoclaved at 121 °C for 15 minutes.

2.3.3 Czapek Dox Agar

Forty-nine grams (49 g) of Czapek Dox agar powder was suspended in 1000 mL of distilled water. The medium was heated and stirred to dissolve the powder completely. Then, the medium was autoclaved at 121 °C for 15 minutes.

2.3.4 Malt Extract Agar

Fifty grams (50 g) of malt extract agar powder was suspended in 1000 mL of distilled water. The medium was heated and stirred to dissolve the powder completely. Then, the medium was autoclaved at 121 °C for 15 minutes.

2.3.5 Yeast Extract Agar

Twenty-three grams (23 g) of yeast extract agar powder was suspended in 1000 mL of distilled water. The medium was heated and stirred to dissolve the powder completely. Then, the medium was autoclaved at 121 °C for 15 minutes.

2.3.6 Potato Dextrose Agar

Thirty-nine grams (39 g) of Potato Dextrose agar was suspended in 1000 mL of distilled water, dissolved in water and autoclaved at 121 °C for 15 minutes.

2.4 Pathogen Isolation

C. coffeicola is a coffee pathogen which exists in the plantation throughout the whole season. Cercospora infected leaf samples were collected at Coffee Research Institute farm during the months of March when the highest infection levels are experienced in Zimbabwe. The infected leaf samples were packed in paper packages and transferred to the laboratory. In the laboratory, one centimeter sections containing half diseased and half health leaf tissue were cut and surface sterilized in 30% sodium hypochlorite solution for about 30 seconds before rinsing three times in distilled water to remove some opportunistic pathogens. The sample was dried on damp filter paper chamber on the laminar airflow. The diseased portions were then transferred to 3 (three) Petri dishes containing PDA. The inoculated Petri dishes were incubated for about 48 hours at a temperature of 25 °C in the constant temperature room, and transferred to the laboratory benches after two days. Cercosporacolonies that developed were characterized, selected and isolated after 4-5 days. The procedure of isolation from PDA, incubation and re-isolation was repeated three times until a pure culture of Cercospora remains in the Petri dishes. On inoculation into the different media treatments, a piece of agar block, approximately 5 × 3 mm in diameter, was cut from a 7-day old PDA culture and transferred into each individual treatment agar (Corn meal agar, Oat meal agar, Czapek Dox agar, Malt extract agar, Yeast extract agar and Potato dextrose agar). The plates were closed tightly and sealed with parafilm.

2.5 Data Collection and Analysis

Data were collected on radial growth estimated by measuring the radius of each colony with a ruler from the centre of the Petri dish along two perpendicular axes (four measurements per dish) at the intervals of 24 hours. Data were collected until the fastest growing treatment reached the perimeter of the Petri dishes. This data was used to calculate the daily rate of growth (mm/day). Data were also recorded on mycelia colour, and texture using a Likert scale where 1 = smooth, 2 = medium and 3 = rough. The data were subjected to the analysis of variance using Genstat 18th edition. The means were separated using the LSD test. Graphs on the growth of Cercospora in different media was plotted using Microsoft Excel.

3. Results

3.1 Growth Characteristics of *C. coffeicola* at 3 and 6 Days after Inoculation (DAI)

The effect of different culture media on radial growth of *C. coffeicola* after 3 and 6 days of incubation are summarised in Table 1. There were significant differences (*p < 0.001*) in mycelia growth due to the effect of different media. Malt extract agar gave the best pathogen growth which had 34.33 mm and 32.00 mm for experiments 1 and 2 respectively, and was significantly different from all the other treatments. Second best medium was Corn meal agar with 28.17 mm in experiment 1 and was not significantly from Czapek Dox and Potato Dextrose agar. In the second experiment 2, PDA gave the second-best growth with 29.17 mm. The least growth of the pathogen was observed in the Oat meal agar for both experiment 1 and 2. In terms of texture Corn Meal Agar showed smooth mycelium while Yeast Extract agar and Czapek Dox Agar had moderate mycelium and Potato Dextrose Agar, Oat Meal Agar and Malt Extract Agar had rougher textured mycelium in appearance in the Petri dishes. In terms of colour deviations, mycelium appears whitish in Corn Meal Agar, light brown in Yeast Extract agar and Czapek Dox Agar. Darker brown colour appears in Potato Dextrose Agar, Oat Meal Agar and Malt. These results are summarised in Table 1.

Table 1. Media options on the growth characteristics of *Cercospora coffeicola*

Treatment	Radial growth				Texture	colour
	DAI 3 (mm)		DAI 6 (mm)			
	Trial 1	Trial 2	Trial 1	Trial 2	Trials 1 and 2	Trials 1 and 2
Corn meal agar	14.5bc	18.3c	27.8b	30.5c	Smooth	White
Oat meal agar	10.0d	11.5f	13.7d	17.8e	Course	Dark brown
Czapek Dox agar	13.0c	17.0d	27.7b	31.5c	Medium	Light brown
Malt extract agar	17.7a	21.3a	34.0a	37.2a	Course	Dark brown
Yeast extract agar	12.8c	15.7e	20.7c	20.8d	Medium	Light brown
Potato dextrose agar	15.2b	19.5b	25.3b	33.8b	Course	Dark brown
P. value	< 0.001	< 0.001	< 0.001	< 0.001	-	-
Grand mean	13.9	17.2	24.9	28.6	-	-
C.V (%)	10.8	5.60	15.3	4.70	-	-
LSD	1.77	1.14	4.50	1.60	-	-

*Means in the same column with different letters are different according to the LSD technique

3.2 Mean Mycelia Growth of Cercospora for Trials 1 and 2

Two experiments were conducted to validate the effect of different media on growth of coffee *Cercospora*. Overall malt extract agar had the highest mean radial growth which differed significantly from the other media treatments ($p < 0.0001$). The least growth was obtained in oat meal agar for both experiments (Figure 1). Mean radial growth for trials 1 and 2 were not significantly ($p < 0.05$) in all nutrient media.

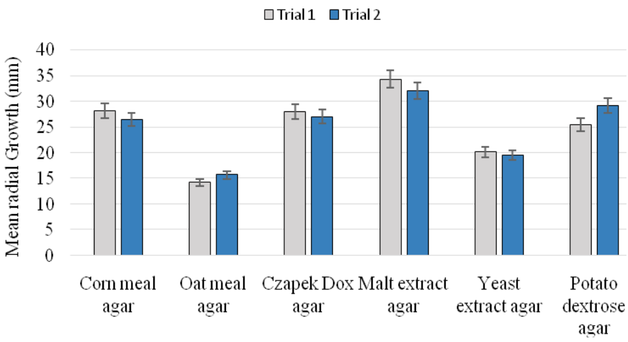

Figure 1. Mean radial growth in different media for the two experiments.

3.3 Percentage Differences in Growth between the Media Treatments against PDA (Standard)

Figure 2 is showing the percentage differences for the different media in relation to the standard media, PDA. Malt extract agar had the greatest positive difference which was 35.5% and 9.4% for trials 1 and 2 respectively. On the other hand, oat meal agar had negative percentage differences of 44% and 46% for trials 1 and 2 respectively.

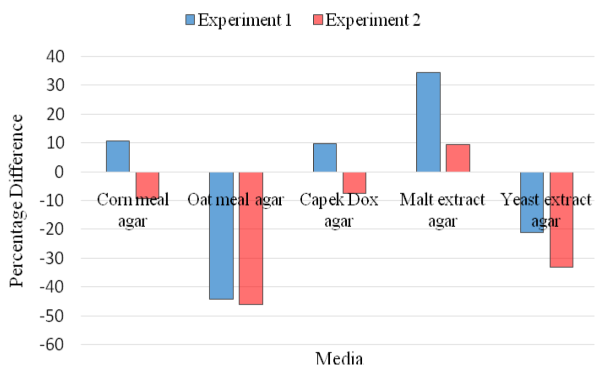

Figure 2. Percentage difference in radial growth as compared with the standard (PDA)

3.4 Nutrient Media Options and Growth Rate of *C. coffeicola*

In trials 1 and 2, there were significant differences in mycelia growth rate due to the effect of different media ($p < 0.001$). Malt extract agar gave the best growth rate of the pathogen (*C. coffeicola*) for both trials (Table 2) and was significantly different ($p < 0.05$) from all other nutrient media. The second-best medium was Corn meal agar (4.64 mm) at 5 days after inoculation and CDA after seven days (4.86 mm) in the first trial. In the second trial, PDA gave the second-best growth 6 and 7 days after inoculation with 5.64 mm and 5.83 mm respectively. The least growth of the pathogen was observed in the Oat meal agar for both experiments throughout the experimental periods.

Table 2. Nutrient media options and growth rate of *C. coffeicola*

Treatment	Mycelium growth rate (mm/day)			
	5 DAI	6 DA1	7 DAI	
	Trial 1	Trial 2	Trial 1	Trial 2
Corn meal agar	4.64b	5.083c	4.62b	5.214d
Oat meal agar	2.28d	2.972e	2.29d	2.905f
Czapek Dox agar	4.61b	5.250c	4.86b	5.571c
Malt meal agar	5.68a	6.194a	5.93a	6.262a
Yeast extract agar	3.21c	3.472d	3.44c	3.476e
Potato dextrose agar	4.12b	5.639b	4.22b	5.833b
P. value	< 0.001	< 0.001	< 0.001	< 0.001
Grand mean	4.14	4.77	4.18	4.88
C.V (%)	15.3	4.7	16.60	3.5
LSD	0.75	0.27	0.82	0.20

*Means with different letters in same column are different according to the LSD technique

3.5 Area under Disease Progress Curves for Experiments 1 and 2

According to the area under disease progress curve (Figures 3 and 4), Malt extract agar had the highest growth for *Cercospora.* Second best was the Czapek Dox agar while least growth was observed from Oatmeal agar for both trials throughout the experimental periods. Malt extract agar supported the best growth of the pathogen in the second experiment and PDA was second best media.

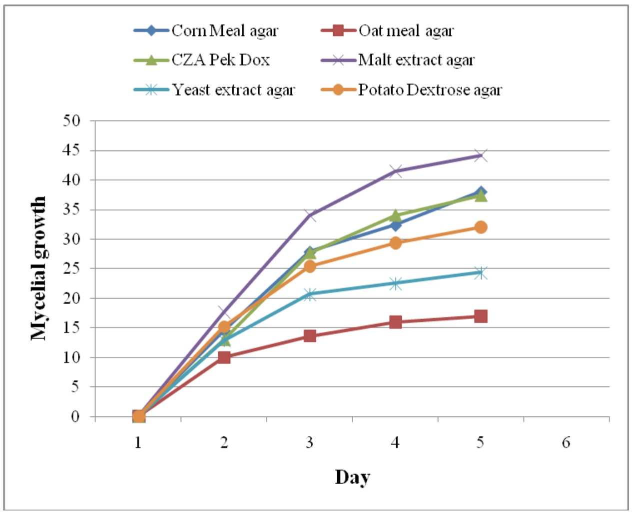

Figure 3. Area Under Disease Progress Curve of the experiment 1.

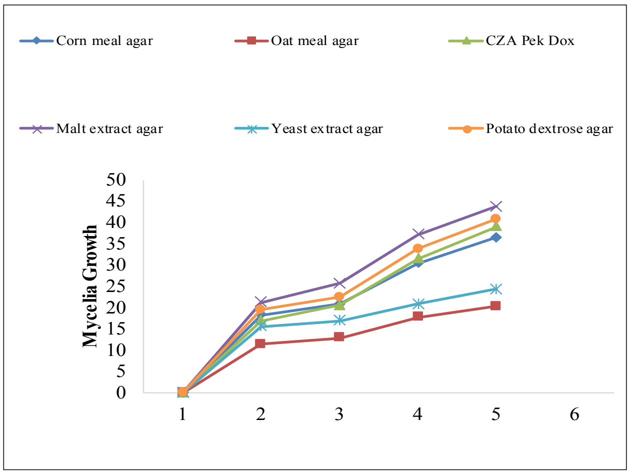

Figure 4. Area Under Disease Progress Curve of the experiment 2.

4. Discussion

Malt extract agar (MEA) had the highest growth of *Cercospora coffeicola* and its performance was significantly different from the rest of the other media treatments, suggesting an excellent support media for early identification of *Cercospora* under laboratory conditions. Early identification of *Cercospora* in the field and the laboratory is key for the implementation of control and regulatory procedures for plant pathogens before crop damage [28,29]. Differences in growth of the pathogen in the different media can be attributed to the variations in the nutritional profiles of the different media [30]. Based on experiments performed, it is the nature and concentration of nitrogen and carbon source and the ratio of C/N that influence fungal growth and sporulation [31,32]. Malt Extract Agar (MEA) contains a high concentration of maltose which makes it suitable for the growth of fungi and molds. Generally, MEA is used as a general-purpose growth media to isolate and cultivate yeasts and molds from a wide range of environmental sources. It contains carbon, protein and nutrient sources essential for fungi growth [31]. Additionally, MEA contains digests of animal tissues (peptones) which provide significant quantities of amino acids and nitrogenous compounds for the growth of *Cercospora coffeicola*. The vegetative growth of a fungus e.g. *Cercospora coffeicola*, lies in its ability to utilize and exploit nitrate, ammonium, and organic sources of nitrogen.

It was interesting to note that MEA had a fastest growth of mycelium with a 34% higher growth than PDA and the findings further indicates that MEA provides conditions allows for faster growth (0.5 to 2 days quicker) in growth than the rest of the other media. This allows timeous crop pathogens identification. On the contrary, oatmeal agar had the slowest growth taking at least 2 days to achieve the same radial growth as MEA. A similar study was conducted by Surendra [16], who observed that *C. arachidicola* of groundnuts takes a maximum of 7 to 10 days to achieve maximum growth in artificial media. This is in agreement with our observations in which MEA reached maximum growth in 7 days after inoculation. In a study by Poornima and Yashoda [33], twelve solid media were evaluated and maximum growth of *C. beticola* was observed on PDA (89.66 mm) and Oat meal agar (81.67 mm), with MEA following behind (79.67 mm). These results are contrary to the findings of this current study, where MEA was the best followed by PDA, with oat meal agar being the least in *Cercospora coffeicola* growth. In another experiment to evaluate the effect of media and light exposure on sporulation of *Cercospora zea maydis*, it was observed that more conidia were produced in V8 agar media when compared with Potato Dextrose agar, tomato juice, coconut water, oat, maize leaf extract [34]. Various *Cercospora* species have different growth performances in different media. However, it is therefore central to understand how each species grows in different media for selection of an optimum growth media.

Corn meal and PDA were the second-best media and this observation was in contradiction with the norm where PDA is generally known as the default culture media for fungi cultures. Studies have shown that growth media for fungi should contain enough sources of carbon (C) and nitrogen (N) required for growth and reproduction [31]. Potato Dextrose Agar (PDA) is composed of dehydrated potato infusion and dextrose that encourage luxuriant fungal growth, with agar as the solidifying agent.

Surendra [16] observed maximum growth of *Cercospora* of groundnuts in Potato dextrose agar better than in oat meal agar. This corroborates with the findings of this study since potato-based media performed better than oatmeal agar. Corn meal agar was second best in experiment 2, performing equally the same with PDA and Czapek Dox agar. Notably, fungal species have different patterns and properties in various probable culture media. *Fusarium oxysporum* grew best in Czapek Dox agar and PDA [35], while *Fusarium adun* also grew best in PDA when compared with Potato sucrose agar, Oatmeal agar, V8-juice agar, Leaf extract agar, Carrot juice agar and Peanut hull extract agar [36]. *Alternaria solani* was found to grow best in Potato Dextrose agar and oat meal agar when tested among different solid and liquid media [37]. Potato Dextrose agar and Potato Dextrose Broth were found to be more favourable to *Fusarium moniliforme* when compared to some solid and liquid media respectively [38]. In one study, growth performances of 30 fungal isolates were examined on different growth media and largest number of isolates significantly grow on malt yeast extract [41]. Here growth was supported by nutrients such as vitamins B1, and B12 which normally support mycelia development.This could be the reasons for growth patterns of *Cercospora coffeicola in culture media.*

Different media produced different colony colours and texture, which ranged from smooth to rough while colours ranged from while generated by corn meal agar to dark brown from MEA and PDA. Malt extract agar is therefore recommended for effective culturing of *Cercospora coffeicola* under laboratory conditions amongst the studied media. This is the first report on studying the growth of *Cercospora* under laboratory conditions. This has implications for the epidemiology of the disease going ahead, forming the basis for morphological and molecular identification of the pathogen to understand.

The trend of the area under disease progress curves showed that Malt extract agar supported maximum growth for the entire experimental periods for both experiments 1 and 2. Czapek Dox agar was second in the experiment 1 while in experiment 2, PDA was the second best after Malt extract agar. The present study results indicated that Malt extract agar proved to be the most suitable media for optimum growth of the pathogen under laboratory experiments. The results of this study contradicts the findings by Surendra [16], who reported that PDA performed the least among other seven media in the growth of *Cercospora arachidicola* of groundnuts. This implies different pathogens in different genera prefer different media for optimum growth.

5. Conclusions and Recommendations

The method used in this study is very simple, low cost, efficient considering resources and reliability over a long period of time [25]. However, it is important to understand that the methods are generally basic, and may need to be complimented by more robust and high throughput technologies. Biochemical and molecular identification methods can be used to fully characterize the pathogen. These methods may be quicker and more reliable as compared to the conventional culture media identification methods [29]. The results of the current study revealed that culture media differed in influencing growth and colony characters of *Cercospora coffeicola*. Out of the six-culture media tested in this study, Malt extract agar was found to be the best suitable media in radial growth of *Cercospora* of coffee. However, potato dextrose agar, corn meal agar and Czapek Dox Agar may be used conservatively for routine cultural and morphological characterisation of *Cercospora coffeicola*. In resource constrained settings we recommend the use of MEA culture-based methods for rapid identification of *Cercospora* of coffee.

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Author Contributions

This work was carried out in collaboration between all authors. Authors NM and CM designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors PC and ZM managed the literature searches and analysis of the study. Author DK managed the experimental process. All authors read and approved the final manuscript.

Conflict of Interest

The authors report no conflict of interest.

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ARTICLE

Analysis of the Effects of Different Tillage Methods on Soil Water Holding Characteristics and Organic Carbon Storage in Farmland

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ABSTRACT

Analyze the impact of tillage on soil carbon storage, define scientific farming methods in Chengdu Plain, China, and provide the basis for regional optimization of farming models and soil improvement. Based on 4 location experiments, two tillage treatments, conventional tillage (CT) and no tillage (NT), were selected to analyze the difference of the impact of tillage on organic carbon. Due to different crop types and soil properties, there are regional differences in the impact of no tillage on soil organic carbon storage, which can significantly improve the surface soil organic carbon storage in various regions. In general, no tillage conservation tillage technology is an effective way to improve surface organic carbon storage.

1. Introduction

Soil is the largest carbon pool of the terrestrial ecosystem [1], which has a great impact on global terrestrial carbon cycle. Farming measures will change the physical properties of soil, affect the decomposition and transformation of organic carbon, and then affect the storage of organic carbon. Many studies show that conservation tillage can increase the content of organic carbon and enhance the effect of soil carbon sequestration. However, the potential of soil carbon sequestration is affected by many factors, such as soil texture, farming methods, planting systems and so on [2]. Carry out comparative networking research on the physical properties of soil in different regions by farming methods will help to understand the differences in the impact of different tillage on soil organic carbon storage, and provide a basis for the promotion of conservation tillage technology in the future [3-5]. Most of the existing studies focus on a single experimental site,

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and the relationship between soil physical properties and organic carbon in different regions and different tillage methods is still unclear [6,7]. In this study, farmland soils in four long-term pilot sites were used as the research object to explore the impact of different regional tillage on organic carbon storage and its driving factors, so as to provide a scientific basis for evaluating the carbon sequestration effect of conservation tillage on farmland soils in different regions. The conclusions of the test results are of universal significance.

2. Materials and Methods

2.1 Overview of the Study Area

GZL, SSY, HLF and SLF test points are selected for the test, which are located in the Chengdu Plain of China and are important areas for the promotion and application of conservation tillage in China. The basic information of each test point is shown in Table 1.

2.2 Experimental Design

The field management of each experimental site was carried out according to local customs, but the amount of straw returned to the field and the amount of fertilizer applied were different. A randomized block design was adopted in the experiment. Conventional tillage (CT) and no tillage (NT) were selected as test treatments, and each treatment was repeated 3 times. Traditional tillage (CT): After harvest, remove the crop straw from the field, use agricultural machinery such as rotary tiller and seeder to plow and sow, and apply fertilizer before sowing; No tillage (NT): Return the harvested crop straw to the field, use the no tillage planter to sow, and at the same time, deeply apply chemical fertilizer on the side of the sowing line. For soil sampling, after the crops are harvested, use the multi-point mixed sampling method to drill 0-10, 10-20, 20-40, 40-60 and 60-80 cm soil samples in the four test sites. Use the section digging method to collect the ring knife samples. All soil samples are put into polyethylene bags and taken back to the room for analysis and determination.

2.3 Index Measurement and Data Processing

Soil compactness: The compactness of 0-45 cm soil layer is measured in the field plot by using the compactness meter (SC900 type). The soil compactness meter automatically counts with the change of soil depth, and reads a value every 2.5 cm, with a horizontal spacing of 10 cm and 9 repetitions [8-10].

Volume weight of soil: ring knife method. Place the ring knife sample in the oven, bake it at 105 °C for 8 h, take it out and place it in the dryer, cool it and weigh it.

Total porosity of soil (%)=(1-soil bulk density/soil density) × 100; The soil density is 2.65 $g \cdot cm^{-3}$.

Soil organic carbon: Vario MACRO cube CHN element analyzer. Pass the air-dried soil sample through a 0.15 mm sieve, remove the carbonate with 1 $mol \cdot L^{-1}$ hydrochloric acid, and then dry it for determination on the machine [11-13].

2.4 Data analysis

Excel 2010 was used for data processing, Sigmaplot14.0 was used to make charts, and the data measurement results were all expressed as mean ± standard deviation. SAS9.1 software was used for one-way ANOVA and two-way ANOVA, LSD method was used for multiple comparisons between different treatments, and t-test was conducted between two treatments at a single test point ($P < 0.05$) [14,15].

Table 1. Basic of the four experimental site.

Site	Annual average temperature (°C)	Annual precipitation (mm)	Crop	Soil type	Soil particle composition (%)		
					Clay (0-0.002 mm)	Silt (0.002-0.05 mm)	Sand (0.05-2 mm)
GZL	5.6	594.8	Spring corn	Cinnamon soil	5.3	59.9	39.1
SSY	7.4	461.8	Spring corn	Cinnamon soil	5.6	63.9	30.5
HLF	11.9	550.0	Winter wheat -Spring corn	Fluvo-aquic soil	4.1	51.4	44.5
SLF	10.7	555.0	Winter wheat	Loessal soil	5.2	73.9	20.9

3. Results

3.1 Effects of Different Tillage Methods on Soil Physical Properties

3.1.1 Soil Bulk Density and Porosity

Different tillage treatments affect soil bulk density, but the degree of influence is different in four test points (Table 2). The soil bulk density of NT treatment group at GZL test site increased by 12.1% compared with that of CT treatment group (P < 0.05); The soil bulk density of NT treatment group in SSY test site was significantly lower than that of CT treatment group (P < 0.05), decreased by 8.2%. There was no significant difference in soil bulk density between CT and NT treatment groups at HLF and SLF test sites (P > 0.05). Compared with soil bulk density, the changing trend of soil total porosity is opposite. The soil porosity of CT treatment group in GZL test site was higher than that of NT treatment group, with a significant difference (P < 0.05). The soil porosity of NT treatment group in SSY test site was 49.4%, which was significantly different from that of CT treatment group (P < 0.05). There was no significant difference between CT and NT treatment groups at HLF and SLF test points (P > 0.05).

Table 2. Soil bulk density and total porosity in 0-10 cm depth under different tillage.

Site	Treatment	Bulk density ($g \cdot cm^{-3}$)	Total porosity (%)
GZL	CT	1.33 ± 0.03	0.49 ± 0.01
	NT	1.49 ± 0.13	0.44 ± 0.05
SSY	CT	1.46 ± 0.02	0.45 ± 0.01
	NT	1.34 ± 0.07	0.49 ± 0.03
HLF	CT	1.46 ± 0.06	0.45 ± 0.02
	NT	1.47 ± 0.01	0.44 ± 0.01
SLF	CT	1.38 ± 0.10	0.47 ± 0.04
	NT	1.36 ± 0.06	0.49 ± 0.02

3.1.2 Soil Compactness

The effects of different tillage treatments on soil compactness at the four test sites were different (Figure 1). The soil compactness of NT treatment group in the whole soil profile of GZL test site was higher than that of CT treatment group in varying degrees; The soil compactness of 0-5 cm topsoil, SSY, HLF and SLF test sites under different tillage treatments had no significant difference (P > 0.05). At 5-25 cm, the soil compactness of NT treatment group at SSY and SLF test sites was significantly higher than that of CT treatment group (P < 0.05), while that of NT treatment group at HLF test sites was higher than that of CT treatment group, with no significant difference (P > 0.05). 25-45 cm, the soil compactness of SSY test site CT>NT (P < 0.05), and the soil compactness of HLF and SLF test sites had no significant difference (P > 0.05).

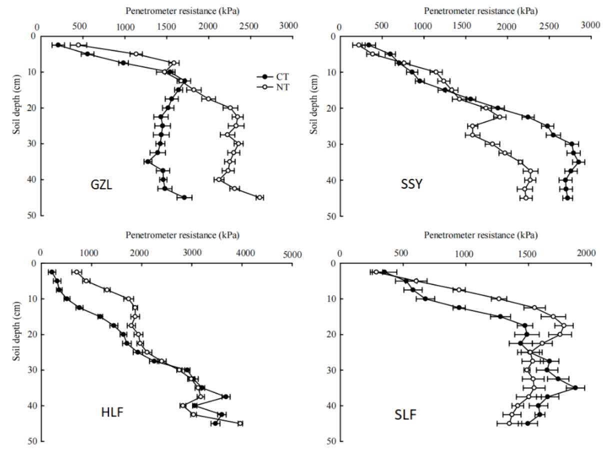

Figure 1. Penetrometer resistance under different tillage.

3.2 Effects of Different Tillage Methods on Soil Organic Carbon

3.2.1 Soil Organic Carbon Content

The content of soil organic carbon under the two tillage treatments decreased with the deepening of soil layers, and the decreasing trend was gradual. There are differences in soil organic carbon content under different tillage treatments in four test sites (Figure 2).

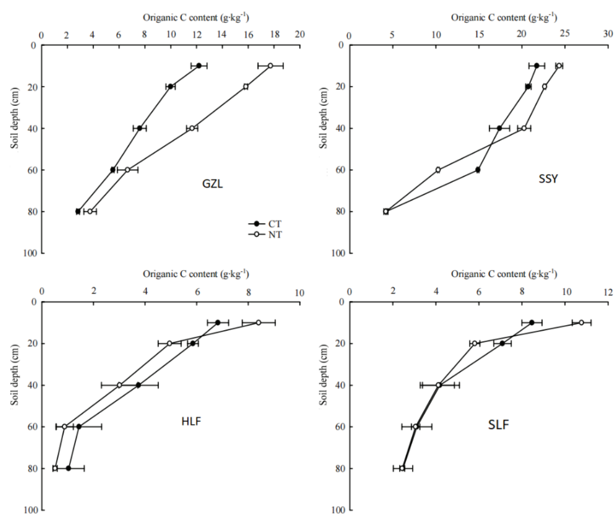

Figure 2. Soil organic carbon contents under different tillage.

The soil organic carbon content of NT treatment group in different soil layers at GZL test site was significantly higher than that of CT treatment group (P < 0.05). In SSY test site, no tillage significantly increased soil organic carbon content in 0-40 cm soil layer ($P > 0.05$), and organic carbon content in soil layer below 40 cm in CT treatment group was higher than that in NT treatment group. In SLF test site, NT treatment group increased the carbon content of 0-10 cm tillage layer, the organic carbon content of 10-20 cm soil layer CT > NT, and the organic carbon content of soil layer below 40cm had no significant difference ($P > 0.05$). Compared with other test sites, the soil organic carbon content of HLF test site under different treatments was significantly different ($P < 0.05$), and the soil organic carbon content of NT treatment group was only higher than that of CT treatment group in the 0-10 cm soil surface layer.

3.2.2 Soil Organic Carbon Storage

According to the two-factor variance analysis, it was found that tillage mode had a very significant impact on soil organic carbon storage ($P < 0.01$), and the experimental site had a significant impact on soil organic carbon storage ($P < 0.05$). Soil organic carbon storage was less affected by the interaction of site and tillage mode ($P > 0.05$). Table 3 shows that the effects of tillage methods on the organic carbon storage of 0-80 cm soil layers at different test sites are different. Compared with the CT treatment group, the NT treatment group increased the organic carbon storage of surface farmland soil. Among them, the organic carbon reserves in 0-10 and 10-20 cm soil layers and the total organic carbon reserves in 0-80 cm soil layers of GZL test site in NT treatment group were significantly higher than those in CT treatment group ($P < 0.05$), with an increase of 45.4%, 58.5% and 7.2% respectively. At SSY test site, the organic carbon storage of 0-10 and 10-20 cm soil layers in NT treatment group increased by 11.9% and 9.2% respectively compared with CT treatment group, but the total organic carbon storage of 0-80 cm soil layers decreased by 26.8%. At SLF test site, the organic carbon storage of NT treatment group in 0-10 cm soil layer was 23.1% higher than that of CT treatment group, and the organic carbon storage of NT treatment group in 0-80 cm soil layer was significantly lower than that of CT treatment group, with a decrease of 31.3%. At SLF test site, the organic carbon storage of 0-10 cm soil layer in NT treatment group increased by 27.2% compared with CT treatment group, and the total organic carbon storage of other soil layers and 0-80 cm soil layer decreased, of which the total organic carbon storage decreased by 23.5%, with significant difference ($P < 0.05$).

Table 3. Soil Organic carbon storage under different tillage.

Site	Treatment	Organic carbon storage($t \cdot hm^{-2}$)					
		0-10 cm	Increased than CT (%)	10-20 cm	Increased than CT (%)	20-40 cm	Increased than CT (%)
GZL	CT	19.04 ± 0.96	45.4	15.99 ± 0.56	58.5	23.21 ± 0.02	–16.5
	NT	27.69 ± 1.52		24.71 ± 0.19		19.37 ± 0.72	
SSY	CT	28.41 ± 1.19	11.9	27.12 ± 0.42	9.2	56.55 ± 4.89	–56.7
	NT	31.81 ± 0.52		29.62 ± 0.14		24.49 ± 1.66	
HLF	CT	10.56 ± 0.63	23.1	9.06 ± 0.32	–15.5	12.14 ± 2.48	–59.1
	NT	12.99 ± 0.99		7.66 ± 0.69		4.96 ± 1.16	
SLF	CT	12.02 ± 0.67	27.2	10.07 ± 0.58	–18.1	12.32 ± 2.67	–49.2
	NT	15.29 ± 0.62		8.25 ± 0.33		6.26 ± 1.12	
GZL	CT	16.87 ± 0.28	–34.4	8.61 ± 0.36	–27.5	83.33 ± 0.89	7.2
	NT	11.07 ± 1.79		6.24 ± 0.81		89.32 ± 0.21	
SSY	CT	28.68 ± 0.28	–26.9	11.69 ± 0.69	–49.4	154.09 ± 3.57	–26.8
	NT	20.97 ± 0.14		5.92 ± 0.09		112.84 ± 1.81	
HLF	CT	3.04 ± 0.31	–52.3	3.36 ± 1.96	–74.7	39.85 ± 1.75	–31.3
	NT	1.45 ± 0.55		0.85 ± 0.14		27.37 ± 2.81	
SLF	CT	9.18 ± 2.06	–49.3	7.28 ± 1.32	–49.1	50.22 ± 4.06	–23.5
	NT	4.65 ± 0.29		3.71 ± 0.17		38.42 ± 0.45	

3.3 Correlation between Climate Factors, Soil Factors and Organic Carbon

There is a correlation between climate factors, soil factors and organic carbon storage under long-term different tillage measures in the four test sites (Table 4). Soil organic carbon storage was significantly positively correlated with saturated water content (P < 0.01), significantly negatively correlated with annual average temperature and annual precipitation (P < 0.01), and significantly negatively correlated with compactness (P < 0.05), but not significantly correlated with bulk density, clay content, silt content, and sand content. At the same time, the saturated water content has a very significant correlation with the annual precipitation and unit weight (P < 0.01), and the compactness has a very significant correlation with the silt content and sand content (P < 0.01).

Table 4. Correlation coefficients between climate factors, soil factors and organic carbon.

	Annual average temperature	Annual precipitation	Bulk density	Clay	Silt	Sand	Saturated moisture	Penetrometer moisture	Organic C storage
Annual average temperature	1								
Annual precipitation	0.126	1							
Bulk density	0.149	0.106	1						
Clay	–0.132	0.101	–0.389	1					
Silt	–0.368	0.023	–0.321	0.902**	1				
Sand	0.337	–0.035	0.335	–0.928**	–0.998**	1			
Saturated moisture	–0.381	–0.589**	–0.524**	0.381	0.317	–0.315	1		
Penetrometer moisture	–0.337	0.298	0.084	–0.308	–0.544**	0.538**	–0.154	1	
Organic C storage	–0.731**	–0.708**	–0.88	0.46	0.218	–0.194	0.627**	–0.538**	1

4. Conclusions

The effects of no tillage on soil bulk density and compactness were different in different regions. No tillage increased soil bulk density and compactness at GZL test site and HLF test site, and decreased soil bulk density at SLF test site and SSY test site.

Compared with traditional tillage, no tillage significantly increased the surface organic carbon storage of 0-10 cm in four experimental sites. Among them, the organic carbon reserves at GZL test point increased by 45.4%, SSY test point increased by 11.9%, HLF test point increased by 23.1%, and SLF test point increased by 27.2% [16-18].

The influence of tillage on the total organic carbon storage in different regions of 0-80 cm soil layer is significantly different. Under no tillage, the organic carbon storage in GZL test site increased by 7.2%, while that in SSY test site, HLF test site and SLF test site decreased by 26.8%, 31.3% and 23.5% respectively.

Long term tillage can affect soil organic carbon storage by adjusting soil water holding capacity and compactness, but the influence degree is different in different regions [19-20]. In general, no tillage is an important measure to improve the topsoil organic carbon storage.

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Conflict of Interest

There is no conflict of interest.

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