# Effect of Niche-fitness under Mulching and Fertilization on Yield of *Lilium Davidii* var. *Unicolor* in Semiarid Regions

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**Abstract**

Strategies of plastic film mulching and fertilization of field in semiarid regions of northwest China are analyzed in this paper. The theory and approach of niche-fitness are introduced into the research on field management. Mathematical model of niche-fitness is constructed to evaluate the adaptive extent of *Lilium davidii* var. *unicolor* to mulching and fertilization and their effect on growth and yield. Compared with those under non-mulching, the plants under mulching had a larger leaf area index (LAI); fertilization increased the plant LAI under both mulching and no-mulching, and the largest LAI was achieved under the combination of mulching and

fertilization. The average values of niche-fitness, bulb yield and water use efficiency (WUE) of *Lilium davidii* var. *unicolor* under mulching were significantly higher than those under non-mulching. Either non-mulching or mulching, the average values of niche-fitness, bulb yield and WUE increased with the increase of fertilizer supply. These findings might be helpful to the farmland mulching-fertilizer management in semiarid regions.

**Keywords:** *Lilium davidii* var. *unicolor*, Niche-fitness, Plastic film mulching, Soil nutrition, Water use efficiency, Bulb yield

## 1. Introduction

In semiarid regions of northwest China, crop production depends on rainfall, and conservation and utilizing of soil water is vital for crop production. In the condition of limited water supply, obtaining higher water use efficiency (WUE) is very important for plant establishment and grain yield formation. (Persand and Knosla, 1999; Aase and Pikul, 2000; Li et al., 2001). Plastic film mulching can reduce water evaporation, and increase the water availability to plants (Cantero-Martinez et al., 1995; O'Leary and Connor, 1997). Studies on vegetable crops have demonstrated that mulching with plastic film is beneficial to crop production with better soil and water conservation, more effective utilization of water and fertilizers, improved soil physical and chemical properties, and the prevention of plant diseases from the soil (Tindall et al., 1991; Green et al., 2003; Scarascia-Mugnozza et al., 2006). It is also known that moderate fertilization in semiarid regions can increase the utilization ratio of water in soil. Olson (1964) made the first attempt to study the relationship between the fertilizer and the water consumption of plants. In the 1970s, Food and Agriculture Organization (FAO) invested in studies on the efficiency of fertilizer in the light of consecutive drought in some African countries to make sure that fertilizer is effective in increasing water utilization ratio and drought-resistance capability of crops. The results of many studies have indicated that moderate fertilization with nitrogen, phosphorous and potassium could improve the state of water content in a crop and enhance the utilization ratio of crop to water in soil under arid and semi-arid condition (Clarke et al., 1990; Egghball and Maranville, 1991; Halvorson and Reule, 1994; Hussain and AI-Jaloud, 1995; Marshner, 1995; Van Schaik et al., 1997; Katerji et al., 1998; Recio et al., 1999; Saneoka et al., 2004). Experiments on the relationship between fertilizer and drought-resistance and high yields under drought conditions were conducted (Guo, 1995; Shiming and Songling, 1995). In fact, water and fertilization factors during crop growth are interrelated. Under certain circumstances, they are complementary and cooperative in the course of crop growth.

*Lilium davidii* var. *unicolor* is one of plants with great economic value due to its applications in food, medicine, and gardening (Niu, 2000). It is one of species in the genus *Lilium* of the family Liliaceae, and it is rich in protein, sugar, vitamins, and mineral nutrients (Wang, 2001). Studies have shown that its bulb is effective in reliveing cough, phlegm, and anxiety symptoms, improving immunity, and preventing tumor development and oxidation, etc (Ma et al., 2005). Its flower contains abundant nutritions, and has become a new food source (Shen, 2008). Though in China, more than ten lily species are known edible, only *Lilium davidii* var. *unicolor* has grown into large scale production. In the semiarid regions of northwest China, *Lilium davidii* var. *unicolor* is even more important to local economy since alternative economic crops are limited by the low, unpredictable water supply and infertile farmland, etc.

In order to thoroughly study the factors of mulching and fertilizer in semiarid farmland, we selected *Lilium davidii* var. *unicolor*, the main economic crop in semiarid regions of Gansu Province, China, as our object. The presented study introduces the niche theory into the study of crop growth systems, examines the implication of niche-fitness (Li and Lin, 1997), and constructs its mathematical model. In this study, a set of mulching-fertilization experiments were conducted to study the biological responses of the leaf area index (LAI) of *Lilium davidii* var. *unicolor* to different mulching-fertilization conditions, and the crop niche-fitness values are analyzed quantitatively. In order to achieve the highest crop yield, the optimum combination of mulching and fertilization are examinined.

## 2. Materials and method

### *2.1 Experimental site*

The experimental site is located in Longzhong mountainous areas, Gansu, northwest China (35°34′—36°26′N, 103°49′—104°34′E). The experimental site is on a 10-degree slope field. This agricultural area has a typical semi-arid climate with an annual average precipitation of 350 mm and annual average temperature of 6.2 °C. About half of precipitation concentrates between July and September, which is also the warm season based on the statistics data of monthly mean temperature in the past 30 years. The soil type of the experimental site is sandy loam with mean bulk density of 1.25 g $cm^{-3}$. Analysis of the soil samples from 0-20 cm depth indicates

that it contains 9.4 g $kg^{-1}$ organic matter, 0.82 g $kg^{-1}$ total N, 0.78 g $kg^{-1}$ total P, 0.075 g $kg^{-1}$ alkali-hydrolyzable N, 0.12 g $kg^{-1}$ rapidly available K, and 0.008 g $kg^{-1}$ rapidly available P. The soil *pH* value is 8.2.

*2.2 Experimental design and treatment*

About 21 g seed bulb was planted on March 15, 2006, and harvested in early November 2008. The experiment was arranged in a randomised complete block design with three replicates of each plot 7 m×4 m. The nine fertilization treatments were applied, which consisted of the combinations of three N/P treatment rates ($(NP)_0$: 0 kg $ha^{-1}$ N and 0 kg $ha^{-1}$ $P_2O_5$; $(NP)_L$: 150 kg $ha^{-1}$ N and 150 kg $ha^{-1}$ $P_2O_5$; $(NP)_H$: 300 kg $ha^{-1}$ N and 300 kg $ha^{-1}$ $P_2O_5$) and three K treatment rates ($K_0$: 0 kg $ha^{-1}$; $K_L$: 60 kg $ha^{-1}$; $K_H$: 120 kg $ha^{-1}$). The N, P and K were applied in forms of ammonium bicarbonate ($NH_4HCO_3$), ammonium hydrogen phosphate ($(NH_4)_2HPO_4$), and potassium sulfate ($K_2SO_4$) mixed properly for each treatment before planting. In 2007 and 2008, the same mixed fertilizer for N, P and K were applied before emergence. For the mulching treatments, 6-μm-thick and 80-cm-wide water permeable plastic films were placed over the soil surface after planting. After emergence, film on top of seedlings was cut to free the seedlings. Plastic films were replaced in early March 2007 and 2008. The non-mulching treatments were used as a control. The planting density was 22.5 plants $m^{-2}$. Prior to the planting, the experiment field was plowed and harrowed. With a manual bunch-planting method, one seed bulb was placed in each hole in the prepared furrow with the seed bulb terminal bud pointing upward and then covered with moist soil. To ensure the uniformity of plant density, all plots were trimmed to the target plant density by thinning at the seedling stage. During the whole growth cycle, supplemental irrigation was not supplied. Weeds were controlled by hand weeding.

*2.3 Measurements*

During the whole growth cycle, the method of timing and positioning was used in observing the fields for field study of *Lilium davidii* var. *unicolor* growth and bulb yield. The observation was carried out once in each growth stage, in which the seedling height, basal diameter, and leaf number were measured. The images of leaves were recorded and then the images were digitized with the SKYE Leaf Area and Root Length Image Analyzer (Model SKYE, Qudao Scientific Equipment Co., Ltd., Beijing) in order to determine the leaf area. At the end of the destructive harvest, plants from each plot of 1.0 $m^2$ were harvested to determine the bulb yield. At the different growth stages of *Lilium davidii* var. *unicolor*, the soil samples from 0 cm to 20 cm depth were collected and air-dried for determination of soil water content (oven drying method), alkali-hydrolyzable nitrogen (alkali-hydrolyzed diffusing method), rapidly available phosphorus (0.5 M sodium bicarbonate ($NaHCO_3^-$), pH8.5-extractable P), and rapidly available potassium (1 N $NH_4OAC$-extractable K). Soil temperature of 10 cm depth was also measured by earth thermometer. WUE is calculated by dividing bulb yields by evapotranspiration. The results are shown in Tables 1, 2, 3 and 4.

*2.4 Statistical analysis*

Data were analysed on SPSS software (Statistics Package for Social Science, SPSS Institute, 1997). All the variables from measurements were analyzed using Univariate process of General Linear Model (GLM). The values of niche-fitness, bulb yield and WUE under mulching condition were compared with those under non-mulching control, using a paired *t*-test.

**3. Niche-fitness model**

*3.1 Constructing niche-fitness model*

In semiarid regions, space–time distribution and their synthesis with ecological factors such as water, soil and fertilizer determine the crop productivity. Meanwhile, the crop growth can adapt to changes in all kinds of ecological factors. The niche theory (Grinnel, 1924; Hutchinson, 1957; Levins, 1968; May, 1974, 1981; Wang, 1995; Odling-Smee et al., 1996; Buggeman and O'Nuallain, 2000) can evaluate the fitness of crops under different cultivation systems by utilizing multi-dimensional resource spectrum. The niche theory is introduced into the research of crop growth system. By taking *Lilium davidii* var. *unicolor* as the object, Hutchinson's (1957) niche concept of *n*-dimensional super-volume is extended. From the perspecttive of agroecology, niche-fitness is a description of the adaptability of a species to its surroundings. The actual resources are often different from a species' optimum requirements in one way or another. In an actual or a modified habitat which suites the species, the population would increase and promote an increase of yield; otherwise, it would decrease and result in a decrease of yield. This is consistent with the concept of niche-fitness.

In this study, *Lilium davidii* var. *unicolor* was used as the study object and the following ecological factors were considered: temperature, soil water content and soil nutrition. The quantitative indices of these factors are marked as $x_1, x_2, \ldots, x_n$, and then the actual resource state $X_t$ is defined as $(x_{t1}, x_{t2}, \ldots, x_{tn})$, which is a point in the

*n*-dimensional resource space. Biologically, a crop will show certain adaptation to variations of each main ecological factor, so the optimum value of main ecological factor *i* can be marked as $x_{ai}(i=1,2,...,n)$. Niche-fitness makes the assumption that species responses to single ecological factor are a single-humped curve (May, 1981), and can be modeled by a bell-shaped curve (Levins, 1968). $X_a=(x_{a1}, x_{a2}, \ldots, x_{an})$ represents the optimum niche point as described by Grubb (1977), and is a quantitative description of species attributes for the optimum ecological condition. $x_{ai}$ can be obtained experimentally in practice. If *n*-dimensional niche region of the crop is noted as $E^n$, then we have $X_t \in E^n$, $X_a \in E^n$. The formula of crop's niche-fitness is:

$$NF = \Phi(X_t, X_a), \quad X_t \in E^n, \quad X_a \in E^n \tag{1}$$

where $NF \in [0,1]$. A larger *NF* value indicates a higher fitness degree, and greater variation of resource state results in wider distribution of *NF* in the interval [0,1]. $\Phi(X_t, X_a)$ is the measurement of the distance or the degree of similarity between two vectors: $X_t=(x_{t1},x_{t2},...x_{tn})$ and $X_a=(x_{a1},x_{a2},...x_{an})$.

In this study, a *NF* model was established as the followings. Assume there are *m* field trials and *n* ecological factors, and the related observation results are as follows:

| No. | Indexes | | | |
|---|---|---|---|---|
| | $x_1$ | $x_2$ | … | $x_n$ |
| 1 | $x_{11}$ | $x_{12}$ | … | $x_{1n}$ |
| 2 | $x_{21}$ | $x_{22}$ | … | $x_{2n}$ |
| ⋮ | | | ⋮ | |
| *i* | $x_{i1}$ | $x_{i2}$ | … | $x_{in}$ |
| ⋮ | | | ⋮ | |
| *m* | $x_{m1}$ | $x_{m2}$ | … | $x_{mn}$ |
| M+1 | $x_{a1}$ | $x_{a2}$ | … | $x_{an}$ |

Where $a=m+1$, and the row *i* of the table records the observed values of each ecological factor under the treatment *i*. The standardized ecological factor $x'_{ij}$ and is defined as:

$$x'_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m+1} x_{ij}} \quad i = 1, 2, \cdots, m \ , \ j = 1, 2, \cdots n \tag{2}$$

$$x'_{aj} = \frac{x_{aj}}{\sum_{i=1}^{m+1} x_{ij}}, \quad j = 1, 2, \cdots n \tag{3}$$

The corresponding model of niche-fitness was established as:

$$NF_i = \frac{1}{n}\sum_{j=1}^{n} \min\left\{x'_{ij} / x'_{aj}, x'_{aj} / x'_{ij}\right\}, \quad i = 1, 2, \cdots, m \tag{4}$$

*3.2 Calculation and analysis of the example*

To apply the model above in this study, let $x_1$ be the soil water content of the 20 cm thick top soil layer, $x_2$ be soil temperature at the 10 cm depth, and $x_3$, $x_4$ and $x_5$ be contents of alkali-hydrolyzable nitrogen (mg $kg^{-1}$), rapidly available phosphorus (mg $kg^{-1}$), and rapidly available potassium (mg $kg^{-1}$), respectively. The observation results of each index are shown in Table 2. Standardize all data in Table 2 according to Eqs. (2) and (3), utilizing Eq. (4), the specific calculation formula is:

$$NF_i = \frac{1}{5}\sum_{j=1}^{5} \min\left\{x'_{ij} / x'_{aj}, x'_{aj} / x'_{ij}\right\} \tag{5}$$

The niche-fitness values are shown in Table 3 according to Eq. (5) and standardized values.

In order to test the validity of the *NF* model as a measure of the degree of similarity of an actual resource state to

the optimum resource state, and to explain its mathematics justification, the geometric parallelism formula (Li and Lin, 1997) are tested and verified as follows:

The absolute difference is repeatedly calculated between $x'_{ij}$ and $x'_{aj}$,

$$\delta_{ij} = \left| x'_{ij} - x'_{aj} \right|, \quad i = 1, 2, \cdots, m, \quad j = 1, 2, \cdots, n \tag{6}$$

$$\delta_{\min} = \min\left\{\delta_{ij}\right\} = \min\left\{\left| x'_{ij} - x'_{aj} \right|\right\} \tag{7}$$

$$\delta_{\max} = \max\left\{\delta_{ij}\right\} = \max\left\{\left| x'_{ij} - x'_{aj} \right|\right\} \tag{8}$$

The corresponding model of niche-fitness was established as:

$$F_i = \frac{1}{n}\sum_{j=1}^{n} \frac{\delta_{\min} + \alpha\delta_{\max}}{\delta_{ij} + \alpha\delta_{\max}}, \quad i = 1, 2, \cdots, m \tag{9}$$

In Eq. 7, $F_i$ stands for the value of niche-fitness under experiment $i$. $F_i \in [0,1]$, and $\alpha$ is the parameter of the model, $\alpha \in [0,1]$. In order to have a reasonable distribution of $F_i$, suppose $\delta_{ij} = \overline{\delta_{ij}}$, then $F_i = 0.5$, i.e.

$$\overline{\delta_{ij}} = \frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n}\delta_{ij}, \quad \frac{\delta_{\min} + \alpha\delta_{\max}}{\overline{\delta_{ij}} + \alpha\delta_{\max}} = 0.5 \tag{10}$$

$\alpha$ can be estimated from the formula.

The calculation results are shown in Table 3.

*3.3 Statistical analysis of the relationship between niche-fitness and bulb yield of Lilium davidii var. unicolor*

To identify the relation between the marketable bulb yield of *Lilium davidii* var. *unicolor* and nitch-fitness $NF_i$, We adopt the linear regression model y=a·*NF*+b and obtain the following formula:

$$y = 116439 \cdot NF_i - 56966, \quad R^2 = 0.9172 \tag{11}$$

where $y$ is the bulb yield of *Lilium davidii* var. *unicolor*.

In comparison, the relation between bulb yield of *Lilium davidii* var. *unicolor* and the fitness $F_i$ can be presented as:

$$y = 129916 \cdot F_i - 53876, R^2 = 0.757 \tag{12}$$

where $y$ is the bulb yield of *Lilium davidii* var. *unicolor*. The two formulas above reflect the statistical law between the bulb yield and its corresponding fitness, which have passed the significance test ($P<0.05$) (Figs. 1 and 2).

The range of *NF* is $0.6021 \le NF \le 0.7298$, and the range of and *F* is $0.5299 \le F \le 0.6125$ (Table 3). The variation range of *NF* is more extensive than that of *F*, and the model based on *F* can not better reflect the increase trends of bulb yield with the increase of fertilizer. For example, under non-mulching condition, bulb yields reach 22842.75 kg ha$^{-1}$, 23412.15 kg ha$^{-1}$ with $(NP)_LK_H$, $(NP)_HK_H$, respectively (Table 3), and the *F* values are 0.6046, 0.5927, respectively, which is not clearly interpretable in biological terms, whereas the counterpart *NF* values are 0.6992, 0.7096, and they are more realistic. A yield regression equation is usually considered well fitted when the coefficient of determination ($R^2$) is high. From the comparison of these models, the *NF* model has a larger coefficient of determination value. All of this indicated that *NF* better reflected the varied differences of fitness under mulching and fertilization condition and the influence of fitness on the yield of *Lilium davidii* var. *unicolor*. *NF* was chosen for depicting the regression relationship between bulb yield and its fitness values. The predicted yields derived from Eq. 11 were also showed in Table 3.

## 4. Results and discussion

*4.1 The quantitative analysis of the niche-fitness of Lilium davidii var. unicolor*

The results show that the *NF* values under non-mulching plots were 0.6131, 0.6327 and 0.6717 with $(NP)_LK_0$, $(NP)_0K_L$ and $(NP)_LK_L$, 0.6507, 0.6546 and 0.7096 with $(NP)_HK_0$, $(NP)_0K_H$ and $(NP)_HK_H$ (Table 3). Compared

with the *NF* values with $(NP)_0K_0$, the *NF* values increased by 1.83 %, 5.08 %, and 11.56 % with $(NP)_LK_0$, $(NP)_0K_L$ and $(NP)_LK_L$, 8.07 %, 8.72 % and 17.85 % with $(NP)_HK_0$, $(NP)_0K_H$ and $A_HB_H$, respectively. Under the mulching treatments, the *NF* values were 0.6631, 0.6705 and 0.6879 with $(NP)_LK_0$, $(NP)_0K_L$ and $(NP)_LK_L$, and 0.6693, 0.6799 and 0.7298 with $(NP)_HK_0$, $(NP)_0K_H$ and $(NP)_HK_H$ (Table 3), respectively. The *NF* values increased by 6.51 %, 7.69 % and 10.49 %, 7.50 %, 9.20 % and 17.22 % compared with that with no fertilizer. Mulching was effective in increasing the *NF* values. Compared with non-mulching control, the average *NF* values under mulching treatments increased by 0.0251, and the difference was also significant ($P<0.05$) (Table 5).

*4.2 Biological growth characteristics*

Florescence is the most productive period of plants growth. Stalk height and basal diameter may serve as measures of growth vigor of plants. With the increasing fertilizer supply, stalk height and basal diameter increased significantly as shown in Table 1. While compared with non-mulching control, the average values of stalk height and basal diameter were increased by 14.09 % and 16.11 %, respectively (Table 1), with mulching. The significant increase in stalk height and basal diameter indicated that fertilization and mulching were effective cultivation practices in improving plant growth.

Variations in LAI of *Lilium davidii* var. *unicolor* describe the surface growth of *Lilium davidii* var. *unicolor* macroscopically. They also show the state of light utilization in crop growth periods (Li and Lin, 1998). The values of LAI of *Lilium davidii* var. *unicolor* under different experimental conditions are shown in Table 1. During the growth stage, the LAI increased from seedling stage to florescence, and decreased from florescence to productive phase. Fertilization treatments had a great influence on LAI: during florescence, the LAI were 0.76, 1.20 and 1.56 $cm^2$ $cm^{-2}$ under non-mulching control, and 0.85, 1.52 and 1.65 $cm^2$ $cm^{-2}$ under mulching treatments, for $(NP)_0K_0$, $(NP)_LK_L$ and $(NP)_HK_H$, respectively. With more fertilizer, LAI increases so that light energy is better utilized. The average values of LAI under non-mulching control in florescence was 1.15 $cm^2$ $cm^{-2}$, while under mulching treatments, it was 1.39 $cm^2$ $cm^{-2}$. The results indicate that mulching can increase the LAI of *Lilium davidii* var. *unicolor*, and then lead to the increase of bulb yield.

*4.3 Bulb yield and WUE*

Bulb yield increased significantly along the increasing fertilizer supply (Table 3). Under the non-mulching condition, compared with $(NP)_0K_0$ plots, the bulb yields with $(NP)_LK_0$, $(NP)_0K_L$ and $(NP)_LK_L$ increased by 6.78 %, 15.31 % and 53.97 %, respectively; and the bulb yields with $(NP)_HK_0$, $(NP)_0K_H$ and $(NP)_HK_H$ increased by 22.64 %, 46.52 % and 74.04 %, respectively. Under mulching treatments, the bulb yields with $(NP)_LK_0$, $(NP)_0K_L$ and $(NP)_LK_L$ were higher by 27.68 %, 34.63 % and 58.38 %, and the bulb yields with $(NP)_HK_0$, $(NP)_0K_H$ and $(NP)_HK_H$ were higher by 34.44 %, 35.05 % and 70.85 %, respectively, compared the bulb yield with $(NP)_0K_0$. The values of bulb yield under mulching treatments were compared with the values under non-mulching control by the paired *t*-test. The average values of the bulb yield under mulching treatments increased by 4587.80 kg $ha^{-1}$. The difference in the bulb yields between mulching treatment and non-mulching control were significant ($P<0.05$) (Table 5), which indicates that mulching increased bulb yield values due to improved micro-environment under mulching cultivation.

In semiarid regions of northwest China, it is not easy to promote agricultural development and increase the crop yield on a large scale due to the limit of water and fertilizer factors in soil. Zhao et al. (1995) suggested that improvement of WUE by better utilization of soil water could be the best way to increase crop yield in these semiarid regions. In the present study, mulching and fertilizer supply could regulate and improve the water utilization. Under the non-mulching condition, the WUEs under $(NP)_LK_0$, $(NP)_0K_L$ and $(NP)_LK_L$ plots were 1.18%, 4.00% and 10.29% higher than that under $(NP)_0K_0$ plots, and the WUEs under $(NP)_HK_0$, $(NP)_0K_H$ and $(NP)_HK_H$ plots were 5.04%, 9.04% and 13.04% higher than that under $(NP)_0K_0$ plots. Under the mulching condition, the WUEs under $(NP)_LK_0$, $(NP)_0K_L$ and $(NP)_LK_L$ plots were 3.40%, 5.92% and 8.83% higher than that under $(NP)_0K_0$ plots, and the WUEs under $(NP)_HK_0$, $(NP)_0K_H$ and $(NP)_HK_H$ plots were 4.88%, 7.46% and 18.20% higher than that under $(NP)_0K_0$ plots (Table 4). The mean WUEs under non-mulching and mulching condition were 16.39 and 19.76 kg $ha^{-1}$ $mm^{-1}$, respectively. The significant difference was found between non-mulching condition and mulching condition (Table 5). WUE reaches its highest under mulching condition with high fertilizer, where the niche-fitness values reach the highest as well. They occur consistently.

## 5. Conclusions

Agricultural production in the semiarid regions of northwest China mainly depends on rainfall. Seasonal rainfall amount and its distribution have a great influence on crop production and economics of this region. Frequent drought is also an important factor limiting crop yields. Rational fertilization and plastic film mulching is the

primary measures to improve yields under limited irrigation in semiarid region, especially in northwest China. Regarding how to improve the values of crop's niche-fitness and yields in semiarid fields with the regulation of fertilizer and mulching, this paper offers a clear theoretical framework and corresponding quantitative method. The niche-fitness of crop is in accordance with the yields, which means the larger the *NF* values, the higher the yield will be. Therefore, we can increase crop yield by enhancing niche-fitness through rational agricultural practices, such as fertilization and mulching. It has great significance in instructing the agriculture practice in the semiarid regions, and it also provides an effective tool for the better application of cultivation systems. The results present a better understanding of mulching–fertilizer management of rainwater-harvesting technology. The research on niche-fitness to crop yields has positive influence on agriculture management in semiarid regions.

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Table 1. The stalk height, basal diameter and leaf area index (±S.D.) of *Lilium davidii* var. *unicolor* seedling under different treatments

| Treatments | | Stalk | | LAI ($cm^2\ cm^{-2}$) | | | |
|---|---|---|---|---|---|---|---|
| | | Height (cm) | Basal diameter (cm) | Seedling | Bud | Florescence | Productive phase |
| Non-mulching | $(NP)_0K_0$ | 30.72±2.66 | 0.810±0.031 | 0.30±0.04 | 0.52±0.05 | 0.76±0.07 | 0.57±0.06 |
| | $(NP)_0K_L$ | 44.24±3.87 | 0.900±0.040 | 0.36±0.04 | 0.67±0.07 | 0.87±0.10 | 0.82±0.06 |
| | $(NP)_0K_H$ | 50.82±3.90 | 0.970±0.028 | 0.38±0.05 | 0.87±0.07 | 1.18±0.11 | 0.98±0.07 |
| | $(NP)_LK_0$ | 39.45±2.94 | 0.875±0.038 | 0.34±0.04 | 0.63±0.12 | 0.83±0.11 | 0.80±0.06 |
| | $(NP)_LK_L$ | 51.50±3.90 | 1.035±0.044 | 0.40±0.04 | 1.00±0.13 | 1.20±0.06 | 1.02±0.06 |
| | $(NP)_LK_H$ | 59.32±4.30 | 1.140±0.054 | 0.45±0.04 | 1.16±0.09 | 1.49±0.06 | 1.23±0.06 |
| | $(NP)_HK_0$ | 46.45±2.10 | 0.925±0.090 | 0.37±0.03 | 0.75±0.10 | 0.98±0.10 | 0.85±0.06 |
| | $(NP)_HK_L$ | 57.41±1.96 | 1.125±0.054 | 0.43±0.04 | 1.08±0.10 | 1.45±0.06 | 1.18±0.05 |
| | $(NP)_HK_H$ | 61.85±4.98 | 1.165±0.035 | 0.47±0.04 | 1.32±0.10 | 1.56±0.10 | 1.34±0.04 |
| | | | | | | | |
| Mulching | $(NP)_0K_0$ | 40.16±3.82 | 0.885±0.074 | 0.36±0.04 | 0.58±0.08 | 0.85±0.10 | 0.62±0.09 |
| | $(NP)_0K_L$ | 54.55±3.21 | 1.050±0.065 | 0.41±0.04 | 0.94±0.07 | 1.28±0.07 | 1.14±0.05 |
| | $(NP)_0K_H$ | 56.68±3.85 | 1.095±0.084 | 0.44±0.04 | 1.08±0.07 | 1.43±0.07 | 1.27±0.04 |
| | $(NP)_LK_0$ | 51.23±3.89 | 0.990±0.054 | 0.40±0.04 | 0.92±0.08 | 1.15±0.07 | 1.04±0.07 |
| | $(NP)_LK_L$ | 57.34±2.15 | 1.255±0.048 | 0.50±0.05 | 1.35±0.13 | 1.52±0.06 | 1.32±0.05 |
| | $(NP)_LK_H$ | 63.72±3.07 | 1.315±0.044 | 0.55±0.04 | 1.43±0.20 | 1.62±0.07 | 1.42±0.04 |
| | $(NP)_HK_0$ | 53.73±5.70 | 1.050±0.065 | 0.42±0.03 | 1.00±0.15 | 1.40±0.06 | 1.25±0.04 |
| | $(NP)_HK_L$ | 60.36±3.85 | 1.270±0.061 | 0.52±0.04 | 1.36±0.09 | 1.57±0.03 | 1.36±0.05 |
| | $(NP)_HK_H$ | 66.25±4.45 | 1.475±0.066 | 0.58±0.03 | 1.50±0.08 | 1.65±0.04 | 1.47±0.05 |

Note: The data in the table are the mean values of collected data during the duration of experiment. The data of stalk height and basal diameter are measured at florescence.

Table 2. The observed index values of ecological factors under different treatments

| Treatments | | $x_1$ (%) | $x_2$ (°C) | $x_3$ ( mg $kg^{-1}$) | $x_4$ ( mg $kg^{-1}$) | $x_5$ ( mg $kg^{-1}$) |
|---|---|---|---|---|---|---|
| Non-mulching | $(NP)_0K_0$ | 13.37 | 20.13 | 44.39 | 13.16 | 103 |
| | $(NP)_0K_L$ | 13.95 | 20.05 | 45.36 | 13.53 | 118 |
| | $(NP)_0K_H$ | 14.41 | 20.76 | 45.44 | 13.67 | 125 |
| | $(NP)_LK_0$ | 13.56 | 18.71 | 53.03 | 15.18 | 100 |
| | $(NP)_LK_L$ | 14.53 | 21.24 | 53.83 | 16.59 | 112 |
| | $(NP)_LK_H$ | 14.97 | 20.87 | 55.01 | 17.71 | 124 |
| | $(NP)_HK_0$ | 13.65 | 18.83 | 65.93 | 17.33 | 101 |
| | $(NP)_HK_L$ | 13.52 | 20.23 | 65.45 | 18.84 | 110 |
| | $(NP)_HK_H$ | 15.18 | 18.89 | 67.97 | 19.06 | 122 |
| Mulching | $(NP)_0K_0$ | 14.27 | 21.06 | 45.73 | 13.71 | 102 |
| | $(NP)_0K_L$ | 15.17 | 22.34 | 46.78 | 14.45 | 117 |
| | $(NP)_0K_H$ | 14.92 | 22.17 | 46.92 | 14.89 | 124 |
| | $(NP)_LK_0$ | 14.88 | 21.84 | 52.66 | 16.76 | 101 |
| | $(NP)_LK_L$ | 15.29 | 21.47 | 53.12 | 17.25 | 115 |
| | $(NP)_LK_H$ | 15.24 | 22.36 | 53.98 | 17.85 | 124 |
| | $(NP)_HK_0$ | 14.15 | 20.03 | 64.56 | 19.73 | 95 |
| | $(NP)_HK_L$ | 14.83 | 20.35 | 64.03 | 20.45 | 112 |
| | $(NP)_HK_H$ | 15.74 | 20.70 | 65.50 | 20.54 | 118 |
| The most suitable values ($x_{ai}$) | | 23.40 | 22.16 | 121.86 | 32.90 | 134 |

Note: The data in the table are the mean values of collected data during the duration of experiment.

Table 3. The $NF_i$, $F_i$, observed bulb yield (±S.D.) and regressive values of yield under different treatments

| Treatments | | $F_i$ | $NF_i$ | Observed bulb yield (kg ha$^{-1}$) | Predicted yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|
| Non-mulching | $(NP)_0K_0$ | 0.5299 | 0.6021 | 13452.40±236.62 | 13141.92 |
| | $(NP)_0K_L$ | 0.5583 | 0.6327 | 15512.51±680.63 | 16704.96 |
| | $(NP)_0K_H$ | 0.5853 | 0.6546 | 19710.24±604.37 | 19254.97 |
| | $(NP)_LK_0$ | 0.5213 | 0.6131 | 14364.60±539.98 | 14422.75 |
| | $(NP)_LK_L$ | 0. 5789 | 0. 6717 | 20712.38±635.49 | 21246.08 |
| | $(NP)_LK_H$ | 0.6046 | 0. 6992 | 22842.75±366.81 | 24448.15 |
| | $(NP)_HK_0$ | 0. 5399 | 0. 6507 | 16498.37±440.67 | 18800.86 |
| | $(NP)_HK_L$ | 0. 5731 | 0. 6843 | 22395.56±382.74 | 22713.21 |
| | $(NP)_HK_H$ | 0. 5927 | 0. 7096 | 23412.15±494.44 | 25659.11 |
| | | | | | |
| Mulching | $(NP)_0K_0$ | 0. 5477 | 0. 6226 | 16298.41±416.49 | 15528.92 |
| | $(NP)_0K_L$ | 0. 5940 | 0. 6705 | 21942.25±439.70 | 21106.35 |
| | $(NP)_0K_H$ | 0. 6104 | 0. 6799 | 22011.52±478.45 | 22200.88 |
| | $(NP)_LK_0$ | 0. 5730 | 0. 6631 | 20810.00±464.86 | 20244.7 |
| | $(NP)_LK_L$ | 0. 5937 | 0. 6879 | 25813.72±348.22 | 23132.39 |
| | $(NP)_LK_H$ | 0. 6221 | 0. 7139 | 26983.65±276.10 | 26159.8 |
| | $(NP)_HK_0$ | 0. 5554 | 0. 6693 | 21911.52±360.24 | 20966.62 |
| | $(NP)_HK_L$ | 0. 5897 | 0. 7069 | 26573.55±507.56 | 25344.73 |
| | $(NP)_HK_H$ | 0. 6125 | 0. 7298 | 27846.53±464.14 | 28011.18 |

Note: The values of $F_i$ and $NF_i$ were obtained from Eqs. [5] and [9], and were average values during the duration of experiment.

Table 4. Water use efficiency (WUE) of *Lilium davidii* var. *unicolor*

| Treatments | Non-mulching | | Mulching | |
|---|---|---|---|---|
| | WUE (kg ha$^{-1}$ mm$^{-1}$) | % | WUE (kg ha$^{-1}$ mm$^{-1}$) | % |
| $(NP)_0K_0$ | 15.25 | 0.00 | 18.24 | 0.00 |
| $(NP)_0K_L$ | 15.86 | 4.00 | 19.32 | 5.92 |
| $(NP)_0K_H$ | 16.63 | 9.04 | 19.60 | 7.46 |
| $(NP)_LK_0$ | 15.43 | 1.18 | 18.86 | 3.40 |
| $(NP)_LK_L$ | 16.82 | 10.29 | 19.85 | 8.83 |
| $(NP)_LK_H$ | 17.15 | 12.46 | 21.05 | 15.41 |
| $(NP)_HK_0$ | 16.02 | 5.04 | 19.13 | 4.88 |
| $(NP)_HK_L$ | 17.07 | 11.93 | 20.20 | 10.75 |
| $(NP)_HK_H$ | 17.24 | 13.04 | 21.56 | 18.20 |

Table 5. Paired samples test of *NF*, bulb yield and WUE under mulching condition with the values under non-mulching control

| Pair variables | Paired differences | | | | | t | d.f. | Significance |
|---|---|---|---|---|---|---|---|---|
| | Mean | S.D. | S.E.M. | 95% confidence interval of the difference | | | | (two-tailed) |
| | | | | Lower | Upper | | | |
| Pair 1: NF under | -2.51E-02 | 1.15E-02 | 3.84E-03 | -3.40E-02 | -1.62E-02 | -6.534 | 8 | 0 |
| non-mulching-mulching | | | | | | | | |
| Pair 2: Bulb yield under | -4587.8 | 1433.595 | 477.865 | -5689.758 | -3485.84 | -9.601 | 8 | 0 |
| non-mulching-mulching | | | | | | | | |
| Pair 3: WUE under | -3.371 | 0.466 | 0.155 | -3.73 | -3.013 | -21.68 | 8 | 0 |
| non-mulching-mulching | | | | | | | | |

Note: E-2=$10^{-2}$, E-3=$10^{-3}$

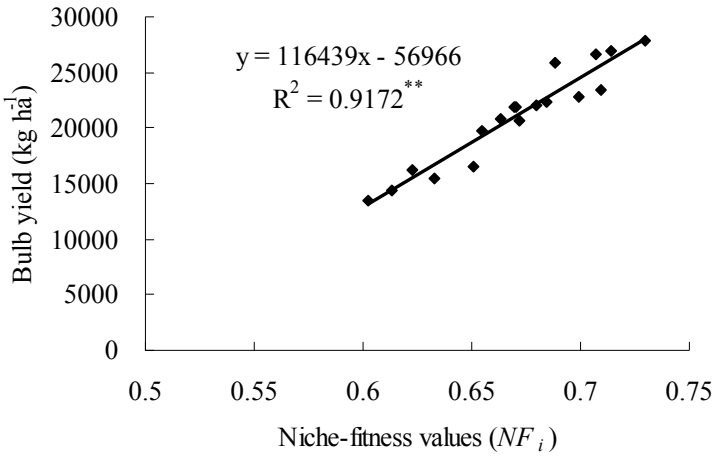


Figure 1. The relationship between niche-fitness values $NF_i$ and bulb yield of *Lilium davidii* var. *unicolor*

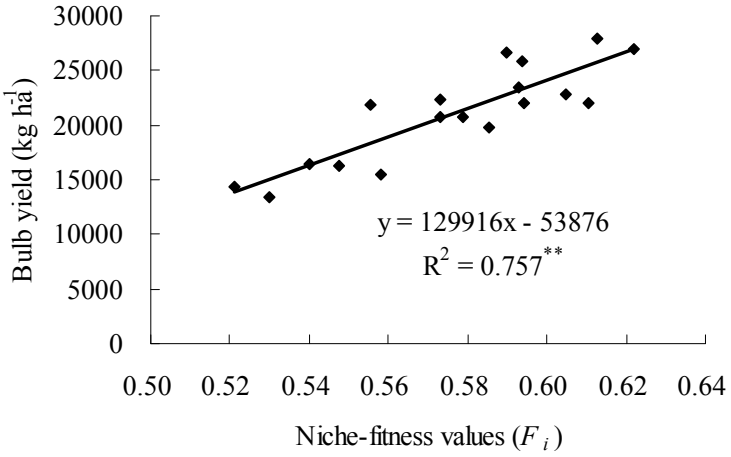


Figure 2. The relationship between niche-fitness values $F_i$ and bulb yield of *Lilium davidii* var. *unicolor*