Effects of Plant Growth Regulators on Fruit Set and Yield of Taiwan *Morus macroura*

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Abstract. In recent years, it is a common phenomenon that Taiwan *Morus macroura* has low fruit set in different mulberry planting areas that occurred popularly in China. This study aims to study the effects of plant growth regulators on fruit set and quality of Taiwan *Morus macroura*. Field experiments were carried out to investigate ten plant growth regulators, treated with 3 concentration gradients. The result shows that six plant growth regulators had better fruit preservation effect, the yield of mulberry which treated with plant growth regulators were significantly higher than that of control groups. To reserve fruit in fruit mulberry production, 85% 2,4-DNa SP with 400000~600000 dilution, 99.9% Boron fertilizer SL with 1500~2500 dilution, Amino acid soluble fertilizer SP with 35000 dilution, 80% DA-6 SL with 50000 dilution, 0.03% NAA SL with 50000 dilution and 8% Chlorophenoxy acetic acid sodium salt SP with 3000~6000 dilution are the best from the standpoint of food safety and economics.

1. Introduction
Mulberry fruit is mature fruit of the mulberry which is a kind of high quality fruit resource, and mulberry was approved as a medicinal and edible homologous plant by the National Ministry of Health\(^[1]\). Mulberry has many characteristics, such as rich nutrition, unique flavor, health effects and so on. With the development of the economy and the improvement of people's living standard, mulberry products will become increasingly popular\(^[2-3]\). Taiwan *Morus macroura* contains rich carbohydrate, organic acid, vitamins, anthocyanin and so on, known as Taiwan long fruit mulberry, also known as super fruit mulberry which tasted sweet and fruity, deeply loved by consumers\(^[4]\). The yield of long fruit mulberry was greatly affected by environmental factors\(^[5]\), it is a common phenomenon that Taiwan *Morus macroura* has low fruit set under bad environmental conditions, that leads to the lower yield. Therefore, how to avoid falling fruit has become an important issue in the production of Taiwan *Morus macroura*. Plant growth regulators (PGRS) have remarkable effect on increasing yield of many kinds of crops which can affect plant endogenous hormone levels in different ways to achieve fruit-preserving effect\(^[6-7]\). At present, there have been no reports on PGRS in Taiwan *Morus macroura*. Therefore, this study is carried out selecting PGRS and appropriate concentration for increasing fruit setting rate and fruit yield, exploring the safe use of PGRS, providing the technical basis for the healthy development of fruit mulberry industry.
2. Materials and Methods

2.1. Experimental materials
These experiments were carried out at the Ganning Base of the Chongqing Three Gorges Academy of Agricultural Sciences. The experimental site is 325 m above sea level. Flat terrain, uniform fertility and consistent field management were chosen for experiments. The test soil was sandy loam soil, with thickness equal to or higher than 1.0 m.

The mulberry variety used in these experiments was Taiwan Morus macroura with planting density of 7500 plants /hm².

2.2. Experimental treatments
In late March of 2016-2019, PGRS were selected for testing listed in table 1. Field experiments were carried out to investigate different PGRS, each of which was treated with 3 concentration gradients. Each concentration was sprayed on forty-nine trees. Control was sprayed by clean water. The shape of the plot was square with basically the same area, around which guardrows established. PGRS were sprayed thoroughly and evenly on the mulberry trees by using electric sprayers after the dew dried up in the morning. The total number of flowering mulberries and dropped fruits were investigated once every 3 days when the mulberry began to drop, and then fruit setting rate and abnormal fruit rate were calculated.

The following is the calculation formula[6-8]: Fruit setting rate(%) = Total number of bear fruits / Total number of flowers×100; Abnormal fruit rate(%)=Total number of abnormal fruits /Total number of bear fruits×100; Growth rate(%)=(Fruit setting rate in treatment area - Fruit setting rate in control area)/ Fruit setting rate in control area×100; Yield growth rate (%)=(Yield per plant in treatment area - Yield per plant in control area)/ Yield per plant in control area×100.

Table 1  Plant growth regulators information

| Treatment | Year   | PGRS                               | Content/Formulation | Manufacturer                                      |
|-----------|--------|------------------------------------|---------------------|---------------------------------------------------|
| A         | 2016-19| 2,4-DNa                            | B≥15% SL            | Chongqing Shuangfeng Chemical Co. Ltd             |
| B         | 2016   | Boron fertilizer                   | Na₂B₄O₇·10H₂O≥99.9%SL | Shandong Qingdao ChengyangChengdongIndustrial park |
| C         | 2016/19| Amino acid soluble fertilizer      | 75% CP              | Shandong Kehai Federation Biotechnology Co. Ltd   |
| D         | 2016/18| GA                                 | Amino-acid≥100g/LCa≥30g/L SP | Shanghai Tongrui Biotechnology Co. Ltd           |
| E         | 2016   | Haikangjudong                      | 0.004%SL            | Helier Pharmaceutical Group Co. Ltd               |
| F         | 2016   | Brassinolide                       | 0.0075%SL           | Chengdu New Chaoyang Biochemistry Co. Ltd        |
| G         | 2016   | Compound sodium nitrophenolate     | 1.40%SL             | Chongqing Shuangfeng Chemical Co. Ltd            |
| H         | 2017/19| DA-6                               | 80%SL               | Chongqing Shuangfeng Chemical Co. Ltd            |
| I         | 2017/19| NAA                                | 0.03% SL            | Shanxi Yonghe Chemical Co. Ltd                   |
| J         | 2018/19| Chlorophenoxyacetic acid sodium salt| 8% SP              | Sichuan Guoguang Agricultural Chemical Co. Ltd   |

2.3. Data analysis
Statistical analysis of data was performed by using Microsoft Office 2010 and IBM SPSS 16.0. One-Way ANOVA was used to conduct difference analysis, and the data was expressed  x±s(n=3).

3. Results and analysis

3.1. Effects of different plant growth regulators on fruit setting rate
Field experiments were carried out to screening the effects of different PGRS on fruit setting rate of Taiwan Morus macroura in spring of 2016 - 2019, the results showed that PGRS which had certain effect on fruit setting rate of Taiwan Morus macroura had different effects on fruit protection, on the whole the fruit setting rate increased with the increase of dosage.

Field trials fruit-preserving efficiency of seven PGRS were tested in 2016, the results (shown in table 2) showed that four PGRS had fruit-preserving effect on Taiwan Morus macroura. The fruit-
preserving efficacy of 85% 2,4-DNa SP was significantly higher than that of other treatments, no significant difference between different concentrations. The fruit-setting rates were more than 98% and growth rates were more than 154.28%, sprayed 85% 2, 4-DNa SP on Taiwan Morus macroura. The fruit-preserving efficacy of Haikangjudong, Boron fertilizer, Amino acid soluble fertilizer with 15000~25000 times solution, and 0.004% Brassinolide SL with 10000000 times solution gained the second field trials fruit-preserving efficacy, there was a noticeable difference in different concentrations, the fruit-setting rates were more than 75.37% and growth rates were more than 92.62%. 0.004% Brassinolide SL with 20000000~30000000 times solution, 1.40% Compound sodium nitrophenolate SL and 75% GA CP gained poor fruit-preserving effect, the fruit-setting rates were less than 75% and growth rates were more than 90%. In terms of abnormal fruit rate, the abnormal fruit rate of mulberry was 2.25%~4.14%, which sprayed 85% 2,4-DNa SP, and increased with the increase of dosage. The abnormal fruit rate of mulberry was 0, of which sprayed by other PGRS.

Field trials fruit-preserving efficiency of five PGRS were tested in 2017, the results (shown in table 3) showed that three PGRS had fruit-preserving effect on Taiwan Morus macroura. The fruit-preserving efficacy of 85% 2,4-DNa SP was significantly higher than that of other treatments, no significant difference between different concentrations. The fruit-setting rates were more than 95.19% and growth rates were more than 167.96% which sprayed 85% 2, 4-DNa SP on Taiwan Morus macroura. The fruit-preserving efficacy of 0.03% NAA SL, 80% DA-6 SL with 50000~100000 times solution gained the second field trials fruit-preserving efficacy, there was a noticeable difference in different concentrations, the fruit-setting rates were more than 70.17% and growth rates were more than 96.04%. 0.0075% Brassinolide SL and 75%GA CP gained poor fruit-preserving effect, the fruit-setting rates were less than or equal to that of the control group. In terms of abnormal fruit rate, the abnormal fruit rate of mulberry was 0.14%~1.05%, which sprayed 85%, 4-DNa SP, and increased with the increase of dosage. The abnormal fruit rate of other treatments was 0.

Field trials fruit-preserving efficiency of five PGRS were tested in 2018, the results (shown in table 4) showed that three PGRS had fruit-preserving effect on Taiwan Morus macroura. The fruit-preserving efficacy of 85% 2,4-DNa SP and 8% Chlorophenoxyacetic acid sodium salt SP was significantly higher than that of other treatments, the fruit-setting rates were more than 91.93% and growth rates were more than 123.97%. The fruit-preserving efficacy of 0.03% NAA SL gained the second field trials fruit-preserving efficacy, there was a noticeable difference in different concentrations, the fruit-setting rate was 69.66%~73.72% and growth rate was 69.71%~ 79.59%. 0.0075% Brassinolide SL and 75% GA CP gained poor fruit-preserving effect, the fruit-setting rates were less than that of the control group. In terms of abnormal fruit rate, the abnormal fruit rate of mulberry was 0.11%, of which sprayed 85% 2, 4-DNa SP with 200000 times solution.

Field trials fruit-preserving efficiency of six PGRS were tested in 2019 on the basis of 2016-2018, the results showed that the fruit-preserving efficacy of different PGRS was different, which had certain fruit-preserving effect on Taiwan Morus macroura (shown in table 5). The fruit-preserving efficacy of 85% 2,4-DNa SP and 8% Chlorophenoxyacetic acid sodium salt SP was significantly higher than that of other treatments, the fruit-setting rates were more than 90.32% and growth rates were more than 128.75%. The fruit-preserving efficacy of Amino acid soluble fertilizer SP, 99.9% Boron fertilizer SL, 80% DA-6 SL and 0.03% NAA SL with 50000~100000 times solution gained the second field trials fruit-preserving efficacy, there was a noticeable difference in different concentrations, the fruit-setting rates were more than 75.98% and growth rates were more than 92.44%. In terms of abnormal fruit rate, the abnormal fruit rate of every treatment was 0.

| Treatment | Dilution multiple | Fruit dropping rate/% | Fruit setting rate/% | Growth rate/% | Abnormal fruit rate/% |
|-----------|-------------------|-----------------------|---------------------|---------------|----------------------|
| A         | 80000             | 1.90±0.34a            | 98.10±0.34a         | 150.73±0.86a  | 2.25±0.17b           |
|           | 70000             | 0.51±0.08a            | 99.49±0.08a         | 154.28±0.20a  | 3.31±0.17c           |
|           | 60000             | 0.30±0.04a            | 99.70±0.04a         | 154.82±0.10a  | 4.14±0.10d           |
| B         | 1500              | 7.20±0.62b            | 92.80±0.62b         | 137.17±1.58b  | 0a                   |
|           | 2500              | 11.73±0.11b           | 88.27±0.11b         | 125.60±0.29b  | 0a                   |
### Table 3 Effects of PGRS on the fruit setting rate of Taiwan *Morus macroura* in 2017

| Treatment | Dilution multiple | Fruit dropping rate/% | Fruit setting rate/% | Growth rate/% | Abnormal fruit rate/% |
|-----------|------------------|-----------------------|---------------------|--------------|----------------------|
| A         | 2000000          | 3.11±0.37 a           | 96.89±0.37 a        | 170.70±0.14a | 0.14±0.01 b          |
|           | 1000000          | 3.24±0.54 a           | 96.76±0.54 a        | 170.34±0.15a | 0.45±0.04 c          |
|           | 500000           | 4.09±0.74 a           | 95.91±0.74 a        | 167.96±0.20a | 1.05±0.03 d          |
| D         | 125000           | 68.04±0.91 j          | 31.96±0.91 h        | -10.70±2.55h | 0 a                  |
|           | 50000            | 85.35±1.50 j          | 14.65±1.50 j        | -59.08±4.19j | 0 a                  |
|           | 100000000        | 73.93±1.20 j          | 26.07±1.20 i        | -27.16±3.34i | 0 a                  |
| F         | 2500000000       | 84.24±1.37 j          | 15.76±1.37 j        | -56.98±3.04j | 0 a                  |
|           | 5000000000       | 84.60±1.09 j          | 15.40±1.09 j        | -55.97±3.82j | 0 a                  |
|           | 200000           | 55.84±1.49 f          | 44.16±1.49 f        | 23.38±4.17f  | 0 a                  |
|           | 100000           | 29.83±0.80 e          | 70.17±0.80 e        | 96.04±2.23e  | 0 a                  |
|           | 50000            | 81.19±0.35 c          | 18.81±0.35 c        | 118.46±0.96c | 0 a                  |
| I         | 100000000        | 17.95±1.36 b          | 82.05±1.36 b        | 129.24±3.79b | 0 a                  |
|           | 500000           | 25.44±1.25 d          | 74.56±1.25 d        | 108.32±3.51d | 0 a                  |
|           | 250000           | 27.69±0.85 de         | 72.31±0.85 de       | 102.03±2.39de| 0 a                  |
|           | CK               | 64.21±1.82 g          | 35.79±1.82 g        | 0 g          | 0 a                  |

Values followed by different letters at the same column indicate significant difference (P<0.05), and those followed by the same letters indicate no significant difference (P≥0.05), the same as below.

### Table 4 Effects of PGRS on the fruit setting rate of Taiwan *Morus macroura* in 2018

| Treatment | Dilution multiple | Fruit dropping rate/% | Fruit setting rate/% | Growth rate/% | Abnormal fruit rate/% |
|-----------|------------------|-----------------------|---------------------|--------------|----------------------|
| A         | 2000000          | 2.17±0.21 ab          | 97.83±0.21 ab       | 138.34±0.50ab| 0.11±0.02 b          |
|           | 4000000          | 3.40±0.47 ab          | 96.60±0.47 ab       | 135.35±1.15ab| 0 a                  |
|           | 6000000          | 6.10±0.85 ab          | 93.90±0.85 ab       | 128.78±2.07ab| 0 a                  |
| D         | 3000000000       | 93.43±2.34 f          | 6.57±2.34 f         | -83.99±5.69f | 0 a                  |
|           | 4000000000       | 93.46±0.86 f          | 6.54±0.86 f         | -84.06±2.10f | 0 a                  |
|           | 5000000000       | 92.69±4.51 f          | 7.31±4.51 f         | -82.18±11.00f| 0 a                  |
|           | 300000000        | 60.58±1.83 d          | 39.42±1.83 d        | -3.95±4.47d  | 0 a                  |
| F         | 3000000000       | 74.98±3.46 e          | 25.02±3.46 e        | -39.04±8.42e | 0 a                  |
|           | 4000000000       | 69.64±0.49 e          | 30.36±0.49 e        | -26.03±2.10e | 0 a                  |
|           | 5000000000       | 29.07±3.70 c          | 70.93±3.70 c        | 72.82±9.02c  | 0 a                  |
| I         | 600000           | 30.34±3.55 c          | 69.66±3.55 c        | 69.71±8.66c  | 0 a                  |
|           | 900000           | 26.28±1.92 c          | 73.72±1.92 c        | 79.59±4.68c  | 0 a                  |
|           | 500000000        | 1.44±1.03 ab          | 98.56±1.03 ab       | 140.12±2.51ab| 0 a                  |
| J         | 400000           | 0.73±0.36 a           | 99.27±0.36 a        | 141.85±0.88a | 0 a                  |
|           | 50000            | 8.07±1.93 b           | 91.93±1.93 b        | 123.97±4.70b | 0 a                  |
|           | CK               | 58.95±0.76 d          | 41.05±0.76 d        | 0 d          | 0 a                  |

### Table 5 Effects of PGRS on the fruit setting rate of Taiwan *Morus macroura* in 2019

| Treatment | Dilution multiple | Fruit dropping rate/% | Fruit setting rate/% | Growth rate/% | Abnormal fruit rate/% |
|-----------|------------------|-----------------------|---------------------|--------------|----------------------|
| A         | 2000000          | 1.27±0.53 a           | 98.73±0.53 a        | 150.05±1.33a | 0 a                  |
|           | 4000000          | 2.21±0.45 a           | 97.79±0.45 a        | 147.69±1.14a | 0 a                  |
|           | 6000000          | 7.19±0.72bc           | 92.81±0.72bc        | 122.07±1.84bc| 0 a                  |
| B         | 200000           | 18.59±2.14gh          | 81.41±2.14gh        | 106.20±5.43gh| 0 a                  |
2500 20.82±1.25ghi 79.18±1.25ghi 100.55±3.17ghi 0
3000 24.02±0.62ij 75.98±0.62ij 97.04±5.64hi 0
25000 22.20±2.23hi 77.80±2.23hi 97.04±5.64hi 0
35000 17.03±1.09fg 82.97±1.09fg 110.15±2.76fg 0
50000 14.35±0.78ef 85.65±0.78ef 116.93±1.99ef 0
80000 17.28±0.58fg 82.72±0.58fg 109.52±1.48fg 0
100000 20.30±0.30ghi 79.70±0.30ghi 101.86±0.76ghi 0
146 2500 20.82±1.25ghi 79.18±1.25ghi 100.55±3.17ghi 0
3000 24.02±0.62ij 75.98±0.62ij 97.04±5.64hi 0
25000 22.20±2.23hi 77.80±2.23hi 97.04±5.64hi 0
35000 17.03±1.09fg 82.97±1.09fg 110.15±2.76fg 0
50000 14.35±0.78ef 85.65±0.78ef 116.93±1.99ef 0
80000 17.28±0.58fg 82.72±0.58fg 109.52±1.48fg 0
100000 20.30±0.30ghi 79.70±0.30ghi 101.86±0.76ghi 0
3.2. Effects of different plant growth regulators on yield
These treatments had a certain effect on the fruit appearance and yield of Taiwan Morus macroura, which sprayed by PGRS (shown in table 6). In terms of fruit exterior appearance, there was no significant difference in the transverse diameter of mulberry fruit, but there was significant difference in the longitudinal diameter of mulberry fruit. The fruit longitudinal diameter of these treatment groups which were treated with 99.9% Boron fertilizer SL with 2000 times solution or Amino acid soluble fertilizer SP with 25000 times solution was higher than that of the control group. In terms of yield, there was no significant difference in single fruit weight of mulberry fruit, the yields of Taiwan Morus macroura which were treated with PGRS were significantly higher than that of control groups, but there was significant difference in yield per plant of mulberry fruit. The yield per plant of Taiwan Morus macroura which were treated with 85% 2,4-DNa SP, 99.9% Boron fertilizer SL with 2000 times solution, 80% DA-6 SL with 50000 times solution, and 8% Chlorophenoxyacetic acid sodium salt SP were significantly higher than that of other treatments, the yield per plant was more than 3.03 kg, and yield growth rates were more than 100.00%.

Table 6 Effects of PGRS on the fruit exterior appearance and yields of the mulberry fruits in 2019

| Treatment | Dilution multiple | Longitudinal diameter/cm | Transverse diameter/cm | Single fruit weight/% | Yield per plant/kg | Yield growth rate/% |
|-----------|------------------|--------------------------|------------------------|----------------------|-------------------|--------------------|
| A         | 2000000          | 11.86±0.73abc           | 1.22±0.017n            | 10.06±0.13n          | 3.49±0.12abc      | 130.11±8.14abc     |
|           | 4000000          | 11.94±1.29abc           | 1.22±0.019n            | 10.62±0.45n          | 3.94±0.25a        | 160.00±16.57a      |
|           | 6000000          | 10.35±0.35c             | 1.17±0.007n            | 9.61±0.33n           | 3.61±0.27abc      | 138.02±17.48abc    |
|           | 2000             | 13.68±1.35ab            | 1.21±0.019n            | 11.40±0.57n          | 3.67±0.97ab       | 142.20±63.65ab     |
| B         | 2500             | 11.47±0.90abc           | 1.20±0.014n            | 10.39±0.42n          | 2.67±0.09cd       | 75.82±5.81cd       |
|           | 3000             | 10.63±0.75c             | 1.21±0.019n            | 10.37±0.72           | 2.32±0.04d        | 52.75±2.75d        |
|           | 2500             | 13.84±1.31a             | 1.23±0.023n            | 11.75±0.68n          | 2.35±0.10d        | 55.16±6.65d        |
| C         | 3500000          | 12.04±0.92abc           | 1.21±0.02n             | 10.84±0.55n          | 3.11±0.25abcd     | 104.84±16.75abcd   |
|           | 4500000          | 11.49±0.38abc           | 1.21±0.012n            | 10.82±0.46n          | 2.89±0.24b        | 90.33±15.33b       |
|           | 500000           | 9.33±0.28c              | 1.19±0.019n            | 9.71±0.39n           | 3.24±0.11abcd     | 113.85±7.19abc     |
| H         | 800000           | 10.83±0.48c             | 1.20±0.012n            | 10.48±0.40n          | 2.92±0.19b        | 92.31±12.51b       |
|           | 1000000          | 10.35±0.53c             | 1.20±0.006n            | 10.72±0.40           | 2.08±0.34c        | 84.84±22.67b       |
|           | 1000000          | 10.52±1.47c             | 1.21±0.018n            | 10.18±0.92           | 3.03±0.22abcd     | 100.00±14.41abcd   |
| I         | 2500000          | 11.08±0.88bc            | 1.20±0.015n            | 10.82±1.43n          | 3.19±0.12abcd     | 110.33±19abc       |
|           | 500000           | 10.93±0.60c             | 1.22±0.014n            | 10.89±0.29           | 2.47±0.15d        | 62.64±9.58d        |
|           | 500000           | 9.78±0.41c              | 1.21±0.014n            | 10.53±0.43           | 3.62±0.06abc      | 138.46±3.96abc     |
| J         | 600000           | 9.73±0.35c              | 1.21±0.025n            | 10.50±0.94           | 3.18±0.25abcd     | 109.67±16.20abcd   |
|           | 700000           | 9.84±0.16e              | 1.21±0.026n            | 10.30±0.55           | 3.22±0.17abcd     | 112.09±11.47abcd   |
| CK        | 9.85±0.26c       | 1.19±0.009n             | 9.74±0.38n             | 1.47±0.08e           | 0.00 e            |                    |

4. Conclusion and Discussion
PGRS used on mulberry were spray applied at both recommended and self-determined concentrations, we found that sprayed 85% 2, 4-DNa SP was harmful to mulberry in 2016, the abnormal fruit rate of mulberry which were sprayed 85% 2, 4-DNa SP with 60000~80000 times solution was 2.25%~4.14%, and the mulberry leaves turned yellow and shrivelled, these indicated that mulberry was sensitive to the concentration change of 85% 2,4-DNa SP. In order to solve the toxicity caused by spraying 85% 2,4-
DNa SP on mulberry trees, the application concentration was reduced in 2017 to 2019. The abnormal fruit rate of mulberry was reduced with decreased concentrations, there was no drug damage to mulberry leaves which were sprayed 85% 2, 4-DNa SP with 200000 times solution in 2017. Reduced the application concentration in 2018-2019, the results showed that there were no obvious abnormalities in leaf shape and leaf color, and there was no abnormal fruit of mulberry which were sprayed 85% 2, 4-DNa SP with 400000~600000times.

Based on field trials four years of field experiments, the results showed that six PGRS had better fruit preservation effects. To reserve fruit in fruit mulberry production, 85% 2,4-DNa SP with 400000~600000 dilution, 99.9% Boron fertilizer SL with 1500~2500 dilution, Amino acid soluble fertilizer SP with 35000 dilution, 80% DA-6 SL with 500000 dilution, 0.03% NAA SL with 50000 dilution and 8% Chlorophenoxyacetic acid sodium salt SP with 3000~6000 dilution are the best from the standpoint of food safety and economics.

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