LETTER

The role of fine management techniques in relation to agricultural pollution and farmer income: the case of the fruit industry

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Abstract

Although agriculture is enjoying booming development it is facing increasingly serious environmental pressures. With increase in the scale of fruit planting, inorganic mineral elements are becoming one of the main sources of non-point pollution. How to achieve sustainable production in agriculture is an issue that needs urgent attention in current rural development. In this paper, based on the micro-production data of peach farmers in 18 prefecture-level provinces, we introduce fine management techniques into the production function to analyze the effects of different techniques and further explore the influence of fine management techniques on fertilizer efficiency. Our findings show that with no change in the degree of investment in fine management techniques the increase in use of chemical fertilizers and pesticides has not only made little contribution to increasing profits but has also resulted in excessive investment in fertilizers that damage the environment. Notably, fine management techniques exerting positive effects on the application efficiency of mineral elements could be an efficient and sustainable way to ease the conflict between environment and profit. However, such techniques are used rarely in practice due to the lack of economic incentives. A brief review of the main measures, such as timely updating of market information, agricultural product branding and socialized services, is offered.

1. Introduction

As a backbone industry that creates wealth for farmers and mitigates poverty in vast rural areas, the fruit industry has long been increasing in importance. In 2019, China’s total fruit output reached 190 million tons, with a cultivation area of about 12.27 million hectares, and both output and cultivation area have been the highest in the world over a number of years. The fruit industry has become China’s third largest agricultural industry after food crops and vegetables. However, there is concern that the development of the fruit industry may suffer from two drawbacks. The first is that while the fruit industry is enjoying rapid development it is facing plenty of competition. According to rural statistical data published by National Bureau of Statistics of China, although yields have grown for 12 consecutive years there has been no increase in net income from cultivation. The strange phenomenon of ‘high production and low income’ is apparent. At the same time, the industry is facing increasing environmental pressures (Wang et al 2018, Yuan and Chen 2019). For example, in 2019, the average amount of fertilizer applied in apple cultivation, 829.65 kg ha⁻¹, was nearly twice as much as that of used for wheat. Surprisingly, the amount of fertilizer applied in Shandong Province had reached 1466.55 kg ha⁻¹. The total amount of fertilizer applied to apple, citrus and orange was about 43 million tons, about 44% of the amount of fertilizer used on wheat. Against the background of rapid growth in the cultivation area, how to promote...
a transition to green production modes, optimize the structure of fruit products and balance the equation between zero growth in fertilizer usage and maintaining growth of farmers’ incomes are significant problems for enhancing the capacity for sustainable development of the fruit industry.

Looking at recent studies (Hansen 2020, Shrestha et al 2020), it is not difficult to see that research on non-point source pollution has mainly focused on field crops, and there is relatively little research on cash crops such as fruit trees. For a long time, the increasing yield of agricultural products has coincided with extensive irrigation and over-fertilization (Maringanti et al 2011, Wiens 2013, Singh et al 2019); thus, the usage of pesticides and fertilizers is commonly considered as the primary source of non-point source pollution with its characteristics of uncertainty and dispersion (Massmann and Holzmann 2015). To date, scholars have studied the formation process, degree and emission efficiency of agricultural non-point source pollution using analysis of agricultural non-point pollution models and the directional distance function (Ni et al 2011, Stuart et al 2014, Duan et al 2016, Norman and Dazzo 2016). In order to reduce non-point source pollution, researchers have carried out a series of systematic studies on the driving factors behind pesticide and fertilizer usage from the perspectives of economic instruments (e.g. individual incentives, price subsidies and environmental taxes) (Bowman and Zilberman 2013, Poppenborg and Koellner 2013, Stuart et al 2014), control (e.g. bans, regulations and types of pesticides) (Vlontzos and Pardalos 2017, Ezbakhe 2018, Expósito and Velasco 2020) and on technical solutions (e.g. application methods, technical training) (Conway and Barbier 2013, Adnan et al 2017).

However, several recent works have focused on analyzing the impact of external factors from the micro-perspective (Khuman et al 2020, Ghafar et al 2021, Tsiboe et al 2021). Few studies have been conducted on choices about the usage of fertilizers and pesticides based on differences in the growth characteristics of crops. Unlike field crops, the growth of fruit trees under natural conditions is often unbalanced in different periods (Cichy et al 2017). Fruit trees are more likely to fruit excessively or to fruit only in alternate years with too rapid growth, which can produce a big drop in commercial profits and the value of cultivation (Spinelli et al 2010, Mendivil et al 2013, Yuan et al 2018). Thus, to help maintain production stability and fruit quality and the absorption of fertilizers, thinning of fruits (flowers), artificial pruning and other fine management techniques usually need to be applied to balance the relation between reproductive growth and vegetative growth (Acampora et al 2013, Duca et al 2016, Assirelli et al 2019). Therefore, with the continued increase in the production of fruit, more labor should be invested in management techniques to guarantee effective usage of minimal elements.

Here, we have combined economic theory with differences in the growth characteristics of crops to address these possibilities of balance between income growth and environmental protection and the possible growth of household income. To achieve these aims, this study carries out a meticulous re-analysis of the marginal outputs of pesticides and fertilizers for a representative group of 18 provinces in China. We innovatively consider the differences in farmers’ cultivation income under different output levels and try to explore the impact of fine management on farmers’ cultivation income and agricultural non-point source pollution. In order to provide a practical basis and reference for promoting the steady increase of farmers’ income and green development of output, we provide a different analytical framework to analyze what could raise household incomes while dampening down the usage of pesticides and fertilizers, considered as the primary sources of non-point source pollution. Our findings will offer inspiration and guidance for policy- and decision-making with the aim of ensuring sustainable agricultural development in developing countries.

2. Methods

2.1. Theoretical framework

Based on Gary’s classical farmer model, we can analyze the mechanism and impact of fine management on farmers’ planting income and non-point source pollution. The farmers’ planting income function is as follows:

\[
Y = P[H] \cdot f[K_{pollution}, H, O] - c[K_{pollution}, H, O]
\]  

(1)

where \(Y\) represents the income from cultivation and \(H\) is the management mode represented by investment in fine management techniques. In addition, this study constructs the quality function of agricultural production \(f\) and the cost function of agricultural production \(c\). \(K_{pollution}\) denotes the inputs considered as the primary sources of non-point source pollution, which includes pesticides and mineral fertilizers and so on. \(O\) denotes other inputs that include labor, size of the planting area, farmers’ education and so on. \(E\) represents the exterior environmental conditions of cultivation, which includes land quality, rainfall and landform. In view of the impact of fine management on the quality of cash crops such as fruits, \(P\) denotes the price function of quality that reflects the sales price of agricultural products at different quality levels. Notably, as decisive techniques governing quality, fine management techniques (e.g. thinning of flowers, artificial pruning) are determining factors of the profits and commercial value of fruit tree cultivation. Under natural conditions, fruit
trees are more likely to fruit only on the premises of investment in the thinning of the flowers (fruits) and pruning. Overall, investment in fine management techniques not only contributes to fruit quality and quantity, but also has a significant impact on income from cultivation, as shown in figure 1.

What’s more, based on maximization of total cultivation income, optimized input conditions of production factors (e.g. fertilizers, pesticides) considered as the primary sources of non-point source pollution can be further derived as follows:

\[ P(H) \cdot \frac{\partial f}{\partial K_{\text{pollution}}} \cdot \frac{\partial f}{\partial H} \cdot \frac{\partial f}{\partial O} \cdot \frac{\partial f}{\partial E} \]

\[ \frac{\partial C(K_{\text{pollution}}, H, O)}{\partial K_{\text{pollution}}} \]  

\[ \theta = \frac{\text{VMP}_K}{P_k} = \left( P(H) \cdot \frac{\partial f}{\partial K_{\text{pollution}}} \cdot \frac{\partial f}{\partial H} \cdot \frac{\partial f}{\partial O} \cdot \frac{\partial f}{\partial E} \right) \left( \frac{\partial C(K_{\text{pollution}}, H, O)}{\partial K_{\text{pollution}}} \right) \]  

As fertilizers and pesticides are indispensable elements in cultivation, how to avoid excessive input is the main goal of prevention and control of non-point source pollution at the present stage. Based on formula (3), it is known that the relative gap between the marginal product value (VMP\_K) and price (P\_k) of production factors is a criterion of whether the input of fertilizers or pesticides is excessive from the view of economics. Firstly, in terms of mineral fertilizers, fine management techniques such as artificial pruning could maintain a balance between reproductive growth and vegetative growth in managing fruit trees, reducing the nutrient outflow and improving the marginal value under the condition of exogenous price. Secondly, in terms of mineral fertilizers, by the thinning and pruning of fruits (flowers), fine management techniques can not only effectively reduce the target area covered by pesticides but also provide good visibility and ventilation for spraying and improve the application efficiency of pesticides.

2.2. Econometric model and variable selection

Following the above analytical framework, this study assesses the effect of fine management techniques on farmers’ cultivation income and the marginal output of chemical fertilizer by constructing the production profit function for farmers. However, if the existing profit model of farmers, which is mostly based on the Cobb–Douglas (C–D) or transcendental logarithm (translog) production function, is applied to assess the marginal output of mineral fertilizers and pesticides while omitting investment in fine management techniques, we would overestimate the marginal output of factors and thus judgments on the application of elements such as pesticides are untrustworthy. Therefore, investment in fine management techniques (e.g. thinning of flowers, artificial pruning) is an integral part of the production function of agriculture in, for example, pear, apple and peach cultivation. Thus, the empirical model of the impact of fine management techniques on the production function of fruit can be set as follows:

\[ Y = f(K, L, O, X) \cdot G(N) \]  

where \( f \) is the output function of farmers and \( G(N) \) is the loss-controlling function. There are various distributions for the loss-controlling function, including the Weibull distribution, logistic distribution and empirical distribution. In order to improve the robustness of the model estimation we choose the exponential distribution to describe the loss-controlling function. \( \phi \) denotes the effects of pesticide inputs on production

\[ G(N) = e^{-\phi N} \]  

As all know, the C–D production function has a strict assumption that the substitution elasticity of
elements is fixed. Under the background of strong heterogeneity of production elements such as the level of agricultural infrastructure and labor resources, the translog production function has some advantages over other production functions such as C–D. What’s more, due to the differences in economic development stage, structure of output and other factors, there are differences in the effect of technology on the improvement of utilization efficiency of production elements, thus demonstrating the non-neutral characteristics of technological progress. Therefore, in the amended translog function that considers the extent of investment in fine management techniques, this study tries to capture the different improvements in utilization efficiency caused by investment in fine management techniques by adding new variables, namely the interactions of the extent of investment in fine management techniques, application of pesticides and fertilizer. The specific model is set as follows:

\[
\ln Y = \beta_0 + \beta_1 \ln K + \beta_2 \ln L + \beta_3 \ln O + \alpha_1 \ln H
+ \alpha_2 (\ln K \cdot \ln H) + \frac{1}{2} \beta_4 (\ln K)^2 + \frac{1}{2} \beta_5 (\ln L)^2
+ \frac{1}{2} \beta_6 (\ln O)^2 + \beta_7 (\ln K \cdot \ln L)
+ \beta_8 (\ln K \cdot \ln O) + \beta_9 (\ln O \cdot \ln L) + \beta_{10} X
+ \beta_{11} N + \alpha_3 (N \cdot \ln H) + \mu. \tag{6}
\]

Therefore, the marginal output of fertilizer is further derived as follows:

\[
\text{VMP}_F = (\beta_1 + \beta_4 \ln K + \beta_7 \ln L + \beta_9 \ln O
+ \alpha_2 \ln H) \cdot \left(\frac{Y}{K}\right). \tag{7}
\]

The explained variable \(Y\) is the production output represented by the total output value in order to avoid potential regional differences. \(O\) represents the other costs incurred, such as maintenance costs, irrigation costs, mechanical costs, etc. \(K\) represents the total amount of mineral fertilizer used, measured by the cost of purchase of mineral fertilizers. \(L\) represents the labor input in processes besides fine management, measured by the sum of the number of workers hired and the farmer’s own labor force. \(N\) represents the quantity of pesticide applied, measured by the purchase price of pesticide. \(X\) is a control variable. According to previous research, factors can be grouped into two classifications. The first variable \(T\) represents crop cultivation characteristics, and is applied to control for the heterogeneity of the crops. \(T_1\) represents the average age of the trees per unit area. \(T_2\) represents the planting density expressed by the average number of trees per unit area. The second variable is regional characteristics, that is a virtual variable which is used to account for the effect of regional characteristics. The second variable ‘pla’ represents the regional characteristics of samples. In the model, farmers are further divided into three groups: eastern provinces, central provinces and western provinces, with the central provinces group considered as the benchmark. Two dummy variables of \(\text{pla}_1\) and \(\text{pla}_2\) are constructed to express the eastern provinces group and the western provinces group. Of these, the eastern provinces group (\(\text{pla}_1 = 1\)) mainly represents farmers who come from eastern provinces and the western provinces group (\(\text{pla}_2 = 1\)), the farmers who come from western provinces.

\(H\) is the investment in fine management techniques, represented by the extent of investment in the thinning of fruits (flowers) and pruning. With the actual cultivation situation, the extent of investment in these techniques is measured by the total labor invested by the farmer (Wang et al 2017). The heterogeneity of the various labor force participants in terms of aptitudes, experience, skills, etc are likely to result in large discrepancies in the potential extent of investment in fine management techniques. According to the study of Yuan and Chen (2019), this paper attempts to avert this endogeneity by treating farmers’ subjective evaluation of the extent of investment in fine management techniques as the instrument. Farmers will grade the evaluation of the extent of investment on a scale of 1–10. Relatively speaking, the higher the subjective evaluation score, the higher the extent of investment in fine management techniques.

It is worth noting that the heterogeneity of the soil fertility is likely to cause large discrepancies in the potential extent of investment in mineral fertilizers. Therefore, if we treat the amount of mineral fertilizer used as the dependent variable and assess the effect of fine management techniques on application of mineral fertilizer and pesticide, endogenous problems may arise with the model. Based on the methods for evaluating soil fertility and the availability of data, this study tries to add an adjustment coefficient expressed by the average soil fertility of towns (townships) for calculating the total amount mineral fertilizer applied (Yuan and Chen 2019). The adjusted indicators are set as follows: \(Q_i\) is the amount of mineral fertilizer used, \(I\) is the coefficient of the average soil fertility of towns where samples were selected, \(W_j\) is the weight index of the \(j\)th nutrient and \(T_j\) is the score value of different nutrient contents. When the contents of different nutrients in soil among sample towns are substituted into formula (8), we can acquire the average soil fertility and comparable amount of mineral fertilizer

\[
K_i = Q_i \times I = Q_i \times \left(\sum_{j=1}^{3} T_j \cdot W_j\right). \tag{8}
\]

What’s more, from the perspective of agro-nomic characteristics, researchers have estimated the minimum amount of nitrogen, phosphorus and potassium required to produce unit yield of peach. Therefore, based on the above data, we can calculate
the residual amount of cause by fertilization, with the rate of absorption and proportion of existing fertilizers, as shown in formula (9). Here, $K_i$ denotes the inputs of $i$ fertilizers, $P$ is the proportion of the nutrient (e.g. nitrogen, phosphorus, potassium) to total fertilizer investment, $Q$ is the yield of peach, $M$ is the demand for nutrients per yield and $L$ is the absorption rate of nutrients. ‘poll’ is the residual amount of nutrients, i.e. the source of non-point pollution

$$poll = K_i \times P - Q \times M = K_i(1 - L). \quad (9)$$

2.3. Data source

Unlike traditional field crops, fine management techniques such as thinning of fruits (flowers) and artificial pruning are applied in the cultivation of fruit trees. In China, peach cultivation has become an important industry with a growing area of 900,000 ha, the third-largest cultivar area in China in 2019. Therefore, the choice of peach trees as the object for this research can reflect to a certain extent the effect of fine management techniques.

Based on related data (e.g. peach yield, size of the planting area, price and farmer household income levels of the different main producing areas) in the China Rural Statistical Yearbook of 2018, this study chose 18 prefecture-level provinces, namely Beijing, Hebei, Shandong, Liaoning, Zhejiang, Jiangsu, Fujian, Hubei, Hunan, Henan, Shaanxi, Shanxi, Anhui, Gansu, Guizhou, Yunnan, Sichuan and Guangzhou, plus 20 townships (towns) as sampling regions, using $K$-means cluster and system sampling. Fully sampled provinces can be divided into three regional groups. The eastern region includes Beijing, Hebei, Shandong, Liaoning, Zhejiang, Jiangsu and Fujian; the central region includes Hubei, Hunan, Henan, Shaanxi, Shanxi and Anhui; the western region includes Gansu, Guizhou, Yunnan, Sichuan and Guangzhou. The contents of the questionnaire consist of major statistical data concerning sales, investment in the main elements, cultivation area of the peach trees, use of technology and family demographics. To ensure quality control of the survey and validity of the data, prior to conducting the survey, investigators received rigorous training related to the content of the questionnaire, along with the meaning, purpose and methods of enquiry for each question. By reading the questions to the respondents, investigators recorded their answers during the survey. Finally, all the responses were collected for a final check. After removal of incomplete and disqualified questionnaires, we obtained a total of 1639 valid completed questionnaires. Figure 2 shows the distribution of the 1639 farming households.

The definition of variables and a statistical description of operational data are shown in table 1 (see the appendix for the table of Tukey’s five-number summary of raw data). The total net income from cultivation is about 60,040 yuan, far higher than the average for crops or corn. As per the previous analysis, the average inputs of fertilizer and pesticide are 9210 and 4150 yuan ha$^{-1}$, respectively, and the input of fertilizer is nearly twice that of pesticide. In the face of growing demand for fruit, farmers have responded by increasing the quantity of fertilizer applied, resulting in an increase in the amount of fertilizer used for 10 consecutive years. However, the increase in fertilizer investment is bound to require farmers to increase investment in pruning and thinning flowers and other technical aspects to ensure output efficiency due to crop production characteristics (Yuan and Chen 2019). The other costs incurred during cultivation amount to 1870 yuan ha$^{-1}$, the average age of the trees is 8.21 years and the average number of trees per farm is 932.73. From the standpoint of labor input, the amount of labor invested in technical processes such as pruning, flower thinning and bagging comprised 161.53 d ha$^{-1}$, accounting for about 54.9% of the total labor input. Notably, regarding technical investments, labor costs keep rising so the labor investment may be reduced in the future.

3. Results

3.1. Analysis of farmers’ cultivation income and non-point source pollution

Based on the fruit yield and quality, from the perspective of peach production, the farming households are divided into four groups: minimum yield (21.18–42.78 t ha$^{-1}$), low yield (42.92–63.01 t ha$^{-1}$), high yield (63.75–82.50 t ha$^{-1}$) and maximum yield (84.00–109.5 t ha$^{-1}$). As seen from the micro-survey statistics for the sampled farmers in table 2, the changes in the yield of peach trees, notably, in the proportion of high-quality peach to total output, show no difference between different groups. Compared with the low-yield group, the high-yield groups do not show a significant difference in the net income from cultivation. In addition, the changing trend of production costs in different groups is similar to the trend of net income and the gap has narrowed between the groups. Under the given technical conditions, production would be improved by increasing the inputs of production elements (e.g. mineral fertilizers), which would greatly increase production costs. However, because of the constraint of nutrients produced by photosynthesis of the peach trees, as investment in mineral fertilizers increases the production of peach shows an increasing trend, whereas the quality and selling prices of peach are declining. Therefore, although the yield of peach in high-yield groups is higher than in low-yield groups who increased investment in fine management techniques, there is no significant difference in the net income from cultivation among the different production groups, due to the different price and quality depending on the various investments in fine management techniques.
Figure 2. Distribution of the sampled farming households by county.

Table 1. Definition and description of model variables.

| Variables         | Detailed variables                                           | Mean   | SD      | Min. | Max. |
|-------------------|--------------------------------------------------------------|--------|---------|------|------|
| Net income (Y)    | Net income of cultivation (1000 yuan ha\(^{-1}\))            | 11.18  | 1.05    | 7.71 | 13.22|
| Pesticide input (N) | Pesticide investment (1000 yuan ha\(^{-1}\))                  | 7.97   | 0.95    | 3.62 | 9.83 |
| Fertilizer input (F) | Mineral fertilizer investment (1000 yuan ha\(^{-1}\))   | 8.77   | 0.89    | 5.93 | 11.18|
| Labor input (L)  | Laboring days for other planting processes (days ha\(^{-1}\)) | 4.36   | 1.04    | 0.14 | 8.19 |
| Other costs (O)   | Other costs incurred during cultivation (1000 yuan ha\(^{-1}\)) | 7.53   | 1.46    | -3.89| 11.35|
| Fine management (H)| Total labor deployed in technical processes (days ha\(^{-1}\)) | 4.58   | 1.01    | -1.56| 8.43 |
| Fine management (H)| Farmers’ evaluation of the degree of fine management | 6.89   | 1.93    | 0    | 10   |
| Cultivation characteristics (T) | Average age of the trees (years) | 8.21   | 4.51    | 1.12 | 30   |
| Cultivation characteristics (T) | Average number of trees per ha | 932.73 | 582.61  | 95.16| 2145.12|
| Regional characteristics (pla) | If farmer comes from eastern provinces, pla1 = 1; if not, pla1 = 0 | 0.43   | 0.50    | 0   | 1   |
| Regional characteristics (pla) | If farmer comes from western provinces, pla2 = 1; if not, pla2 = 0 | 0.35   | 0.48    | 0   | 1   |

Note: The calculations are based on survey data. The values for net income, pesticide, fertilizer, labor, other costs and fine management are all shown in logarithmic form.

However, whether the investments in fine management techniques will affect the profit needs further measurement and analysis.

Under the given technical conditions, to produce 100 kg of peaches, the base consumption of nitrogen (N), phosphorus (P) and potassium (K) is about 500 g, 200 g and 650 g, respectively (Jiang et al 2003, CARS 2017). However, if we further introduce tree growth, defoliation and fallen flowers into the calculation, the base consumption of N, P and K increases to around 880 g, 200 g and 850 g, respectively, as shown in table 3 (El-Jendoubi et al 2013). When urea, calcium superphosphate and potassium sulfate are extensively used for agricultural production, using the basic ingredients and molecular formulae of these, we can approximately estimate that the proportion of nutrients N, P and K contained in fertilizers is about 46%, 7.8% and 41%, respectively. Notably, for compound fertilizers, the content of each of the nutrients N, P and K is 15% in the vast majority of cases. According to the growth of various cultivated varieties of peach, in most instances, without

7 In this paper, nitrogen fertilizer is represented by urea, the chemical formula of which is CH\(_4\)N\(_2\)O, potash fertilizer is represented by potassium sulfate, the chemical formula of which is K\(_2\)SO\(_4\), and phosphatic fertilizer is represented by calcium superphosphate, the basic ingredient of which is phosphoric anhydride (P\(_2\)O\(_5\)).
including the differences in absorption rate during seasons, we can obtain that the absorption rate of nutrients N, P and K is about 50%, 30%, and 40%, respectively (Hiraoka and Umemiya 2000, Tagliavini and Marangoni 2002, CARS 2017). Thus, if farmers apply a set of straight fertilizers including urea, potassium sulfate and calcium superphosphate, it can be seen that the amount of urea, calcium superphosphate and potassium sulfate applied is 3826 g, 8547 g and 5182 g, respectively. After the peaches have been harvested, the residual amounts are 1913 g, 2564 g and 2073 g, respectively. In cases where compound fertilizer was applied, the application and residual amounts of fertilizer are both larger when straight fertilizers are used, as shown in figure 3. Therefore, with the increase in profit and quantity due to over-fertilization, the traditional mode of cultivation is polluting the environment beyond redemption, underscoring the need for more fine management.

3.2. Estimation of the effect of fine management investments on income and fertilizer application efficiency

The estimates of different models are shown in table 4. Model 1 is the C–D production function; the others are translog production functions. Compared with the traditional C–D production function model, the goodness of fit and the significance of the variables were improved in the translog production function model that considers the extent of investment in fine management techniques and controls other related factors. The results of the White test passed the significance test, showing that with significant heteroscedasticity in the estimation model of farmers’ incomes, the weighted least squares (WLS) model and the generalized method of moments (GMM) model should be used separately to estimate the outcome. What’s more, the results of the Hausman test show that endogenous problems did arise with the key explanatory variables. The goodness of fit of the model where investment in fine management techniques and controls other related factors were improved in the translog production function model that considers the extent of investment in fine management techniques and controls other related factors. The results of the White test passed the significance test, showing that with significant heteroscedasticity in the estimation model of farmers’ incomes, the weighted least squares (WLS) model and the generalized method of moments (GMM) model should be used separately to estimate the outcome. What’s more, the results of the Hausman test show that endogenous problems did arise with the key explanatory variables. The goodness of fit of the model where investment in fine management techniques is represented by the instrument is obviously higher than that of the model that considers the amount of labor. Notably, as an important basis for judgment, the explanatory power of instrument proved strongest. Based on the above results, we chose to analyze the estimated results of the model with the instrument considered.

When the relevant coefficients are substituted into the previous formula, the average marginal output of the elements including the mineral fertilizers, pesticides and investment in fine management techniques...

| Group                        | Net income | Annual value | Costs |
|------------------------------|------------|--------------|-------|
| Production of peach (t ha⁻¹) |            |              |       |
| 1                            | 21.18–42.78| 106.63       | 135.71| 29.08 |
| 2                            | 42.92–63.01| 97.80        | 130.22| 32.44 |
| 3                            | 63.75–82.50| 99.53        | 135.41| 35.88 |
| 4                            | 84.00–109.5| 106.33       | 147.05| 40.72 |
| Proportion of high-quality peach (%) |          |              |       |
| 1                            | 0%–50%     | 40.27        | 57.87 | 17.60 |
| 2                            | 50.1%–60%  | 42.93        | 55.50 | 12.57 |
| 3                            | 60.1%–80%  | 44.94        | 58.44 | 13.50 |
| 4                            | 80.1%–100% | 41.38        | 59.88 | 18.50 |

Table 2. Description of the costs and benefits among different groups (1000 yuan ha⁻¹).

Table 3. Descriptive statistics for input and utilization of fertilizers (nutrients N, P and K).

| Type of fertilizer | Absorption rate (%) | Content proportion (%) | Amount applied (g) | Residual amount of fertilizer (g) |
|--------------------|---------------------|------------------------|-------------------|----------------------------------|
| Straight fertilizer|                     |                        |                   |                                  |
| Urea               |                      |                        |                   |                                  |
| Calcium superphosphate |                   |                        |                   |                                  |
| Potassium sulfate  |                      |                        |                   |                                  |
| Compound fertilizer|                     |                        |                   |                                  |
| Urea               |                      |                        |                   |                                  |
| Calcium superphosphate |                   |                        |                   |                                  |
| Potassium sulfate  |                      |                        |                   |                                  |

Notes:
- The absorption rate, which depends on the application behavior of farmers and natural conditions, may be different between seasons.
- Given obvious differences in soil fertility between regions, this paper assumes for explanatory purposes that the basic nutrients are all only use the annual average utilization rate for demonstration.
- Expressed by the maximum of the amounts of nutrients applied. In order to meet to a plant growing, the minimal application amounts should not be lower than the maximum of the base consumption of nutrients, with fixed proportions of nutrients.
- For the purposes of illustration we calculate the residual amount of fertilizer based on the nutrients individually.
can be obtained. The estimated marginal outputs for investment in fine management techniques is $-0.2471$, meaning that with increasing investment of farmers in fine management techniques, the profit from cultivation will decline. Against the background of asymmetrical information concerning the quality of agricultural products, consumers try to avoid the risk of buying low-quality products at a high price by giving a lower price for any product, which leads to the commercial price of products being lower than the real value. Although the marginal output of the mineral fertilizers and pesticides is significantly positive at a confidence level of 1% or 5%, showing to a certain extent that pesticides and mineral fertilizers were not excessively invested in by the sampled farmers, it is notable that these values depend on not only...
the amount of element but also the investment in fine management techniques.

Under the given investment in fine management techniques, the increase of investment in mineral fertilizers and pesticides will further reduce the profit of cultivation, which is comparable to the previous analysis. What’s more, as mentioned above, the growth of fruit trees is often unbalanced in different periods. It is necessary to take measures such as pruning and thinning to respond to this unbalanced development that will have a negative impact on the commercial value of fruit tree cultivation. In addition, the increases in labor input and other costs also have significant positive effects on the profit of cultivation. Although most fruit cultivation processes, such as fruit/flower thinning and pruning, are typically labor-intensive, the increase in other costs (e.g. mechanical costs, fuel costs, electricity costs) can effectively reduce cost of labor in the processes where substitution of machinery for manual labor is easily realized.

With the exception of the model that considers the instrument, this study further redefines the key variable $H$ represented by the ratio of the labor involved in fine management processes to the total input of labor in order to examine the robustness and reliability of the above estimated results. According to the characteristics of cultivation, the cultivation processes can be divided into two categories: fine management and basic management. The fine management processes include fruit/flower thinning and pruning. The basic processes include picking, pesticide application, land preparation, bagging and fertilizer application. With the amount of labor invested in the different processes, we can acquire the value of the variable $H$. The estimated results of new models are shown in table 5.

Models 6 and 7 are translog production models and the difference between models is in whether cultivation characteristics, regional characteristics and heteroscedasticity are controlled. The estimated coefficients and significance levels of the main explanatory variables, such as the degree of investment in fine management techniques, are consistent with the above conclusions. Therefore, the effect of the degree of investment in fine management techniques on peach production was confirmed, indicating that the empirical results in this study are robust and reliable.

### 3.3. Comparison of the marginal returns of mineral elements under different production levels

According to the production of sampled farmers and the above results that consider the investment in fine management techniques, this paper further divides the sampled farmers into four groups, minimum yield (21.18–42.78 t ha$^{-1}$), low yield (42.92–63.01 t ha$^{-1}$), high yield (63.75–82.50 t ha$^{-1}$) and maximum yield (84.00–109.5 t ha$^{-1}$), in order to compare on the marginal output of mineral elements across different production levels. By carrying out $t$-tests on the average values of different production groups shown in table 6, we find that the different groups also have distinct differences in the level of investment in mineral fertilizer per unit profit, and the marginal output of mineral fertilizer shows a declining trend, as verified by the analysis of variance. With increase in production, unit profit requires more mineral fertilizer invested in cultivation.

As for pesticide application, although the coefficient is significantly negative at a confidence level of 1%, the interaction coefficients of the degree of investment in fine management techniques and

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**Table 5. Results of robustness test of production function.**

| Variables          | Model 6       | Model 7       |
|--------------------|---------------|---------------|
|                    | Coef.        | SE            | Coef.            | SE            |
| lnH                | $-0.748^{**}$| $(-0.344)$    | $-0.610^*$       | $(-0.352)$    |
| lnF                | $-0.001^{**}$| $(0.064)$     | $-0.001^*$       | $(0.065)$     |
| lnL                | $-0.062$      | $(-0.110)$    | $-0.037$         | $(-0.109)$    |
| lnO                | 0.171         | $(-0.273)$    | 0.144            | $(-0.271)$    |
| $N$                | 0.096*        | $(-0.048)$    | 0.116*           | $(-0.052)$    |
| lnH $\times$ lnF   | 0.119***      | $(-0.060)$    | $-0.085^{**}$    | $(0.042)$     |
| lnH $\times$ N     | $-0.001^*$    | $(0.005)$     | $-0.002^{**}$    | $(0.001)$     |
| lnF $\times$ lnF   | $0.035^{***}$ | $(-0.005)$    | $0.033^{***}$    | $(-0.005)$    |
| lnL $\times$ lnL   | 0.029         | $(-0.029)$    | 0.039            | $(-0.029)$    |
| lnO $\times$ lnO   | $-0.015^{**}$ | $(-0.006)$    | $-0.015^{**}$    | $(0.006)$     |
| lnF $\times$ lnO   | $-0.056$      | $(-0.034)$    | $-0.053$         | $(-0.034)$    |
| lnO $\times$ lnL   | $-0.030^{**}$ | $(-0.012)$    | $-0.027^{**}$    | $(0.012)$     |
| CoNS               | 0.067**       | $(-0.023)$    | 0.053**          | $(0.023)$     |
| Cons               | 7.455***      | $(0.684)$     | 7.605***         | $(0.692)$     |
| Cultivation char.  | Uncontrolled  | Controlled    |
| Regional char.     | Uncontrolled  | Controlled    |
| Heteroscedasticity | Untreated     | Treated       |
| $R^2$              | 0.485         | 0.497         |

Note: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$; the robust standard errors are given in parentheses.
Table 6. Comparison of the marginal returns under different production levels.

| Production groups | Mean Difference in mean among groups (T-test) | Input of unit profit |
|-------------------|---------------------------------------------|---------------------|
|                   | Marginal outputs                             | Input of unit profit |
| Fertilizer        |                                             |                     |
| Full samples (t ha\(^{-1}\)) | 0.0286                                      | 48.2323             |
| 1                 | 0.0309                                       | 42.2680             |
| 2                 | 0.0293                                       | 46.3256             |
| 3                 | 0.0282                                       | 51.3650             |
| 4                 | 0.0261                                       | 53.2635             |
| Pesticide         |                                             |                     |
| Full samples (t ha\(^{-1}\)) | 0.4232                                       | 3.7808              |
| 1                 | 0.4325                                       | 3.6653              |
| 2                 | 0.4307                                       | 3.6532              |
| 3                 | 0.4131                                       | 3.8652              |
| 4                 | 0.4136                                       | 3.9911              |

Note: *p < 0.1, **p < 0.05, ***p < 0.01.

Application of pesticide are significantly positive, meaning that with increased investment in fine management techniques, the marginal output of the pesticides will increase. Specifically, the marginal output of the pesticides for the minimum-yield, low-yield, high-yield and maximum-yield groups are 0.4325, 0.4307, 0.4131 and 0.4136, respectively. With the increase in production, the marginal output of pesticides seems to show a declining trend, and larger differences would exist in the different groups. Although the average value for marginal output of pesticides for the minimum-yield group is 0.0189 units higher than the value for the maximum-yield group, from the results of t-test the differences in the marginal outputs were not significant in all cases. Compared with the high-yield and maximum-yield farmers, the minimum-yield and low-yield farmers often invest a larger amount in fine management techniques, which not only improves peach quality but also exacerbates the losses from disasters, such as hail, pests and diseases. Therefore, farmers try to avoid the potential risks by increasing the frequency of pesticide application, which leads to differences that are not statistically significant.

### 4. Discussion

Against the background of the rapid development of the modern agricultural industrial base and the consequent agricultural benefits, China’s fruit industry has developed rapidly, the regional layout is more optimized, associated industries are more prominent and the industrial benefits are more obvious. Fruit cultivation has become an important industry, promoting changes in agricultural structure, regional economic development, alleviation of farmers’ poverty and increased income. At present, fruit is the third largest agricultural planting industry after grain and vegetables. The total area of orchards and the total fruit output rank first in the world all year round. With the continuous development of China’s social economy, people’s living standards and quality of life are also gradually improving and more attention is being paid to healthy eating, so fruit is bound to become an indispensable consumer item.

Against the background of rural revitalization, the government should take a set of steps to provide economic incentives for farmers and improve investment in fine management techniques. Specifically, the sustainable development of the fruit industry requires the existing difficulties and future goals to be considered. Notably, the misunderstanding that maintaining production growth is reliant on over-fertilization should be challenged. Second, under current market conditions, for farmers with comparatively limited resources it is almost impossible to capture market changes and respond in time. Therefore, up-to-date information about price and demand should be continuously provided to farmers. Third, investment in fine management techniques should be expanded through market forces, with improvements in agricultural product branding being established step by step in order to achieve high quality and good prices, ensuring a long-term economic boost. Furthermore, through the formation of regional professional technical service organizations, we can make up for the disadvantages (e.g. insufficient physical strength, low skill levels) farmers face in technical investment.

Under the influence of the aim for a long-term increase in yield, some locations have problems of blind planting and extensive management, poorly adaptable varieties and a low degree of standardization, resulting in low internal quality. The degree of commercialization of post-harvest
grading and packaging is low, and brand awareness is not strong, resulting in a low-quality commodity. Management of the application of pesticides and chemical fertilizers is unscientific, the excessive expansion of individual varieties in individual areas has been banned repeatedly and the bottom-line standard of fruit quality and safety has not been fully met. In the future, the development of fruit products will focus on planning of planting and product safety and the differences in investment in fine management techniques across individual farmers should be considered. More detailed research is required to understand the reasons for the underlying causes of heterogeneity in technical investment.

5. Conclusions

With increasing internal and external pressures, the fruit industry badly needs ‘supply side’ reform. As an important starting point for implementing green production methods and optimizing the structure of agricultural products, the degree of investment in fine management techniques is directly related to the success of reforms. Therefore, this paper captures the role played by fine management techniques in fruit production, based on field research data for 18 main peach-producing provinces in China.

Complementary to existing studies, we explore the influence of technical investments on production and re-evaluate the marginal output of factors such as fertilizers and pesticides by introducing fine management techniques into an amended trans-log production function. Through theoretical and empirical research, this study primarily draws the following conclusions. First, for fruits (e.g. apple, peach, pear, etc), the maintained growth of yield has coincided with small cultivation profits. Meanwhile, with the continued increase in the application of chemical pesticides and fertilizers in fruit cultivation, the marginal output of both fertilizers and pesticides is declining. Although the investment in fine management techniques has a significant positive effect on the application efficiency of factors, the improvement in fine management techniques invested by farmers is small in cases where the strange phenomenon of ‘high quality and good prices’ is not apparent and there is a lack of economic incentives. The maintained growth of yield may be a potential challenge if we are to address environmental pressures under the existing technical investments.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

CRediT authorship contribution statement

Bin Yuan: data curation, formal analysis, investigation, methodology, resources, software, validation, writing–original draft preparation. Fangzhou Yue: writing–review and editing, data curation. Yuhu Cui: formal analysis, supervision, visualization. Chao Chen: funding acquisition, investigation, project administration, resources, writing–review and editing.

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Appendix. Five-number summary of variables (per hectare)

| Variables                                      | Minimum | Lower-hinge | Median  | Upper-hinge | Maximum |
|------------------------------------------------|---------|-------------|---------|-------------|---------|
| Net income (1000 yuan ha$^{-1}$)              | 2250    | 39 250.1    | 75 075.1| 148 775.1   | 552 562.5|
| Pesticide input (1000 yuan ha$^{-1}$)         | 0       | 1875.1      | 3061.2  | 5625.1      | 18 750.1|
| Fertilizer input (1000 yuan ha$^{-1}$)        | 0       | 3750.1      | 7000    | 12 000.1    | 71 739.1|
| Labor input (days ha$^{-1}$)                  | 0       | 41.3        | 2118    | 3447.1      | 3608.8  |
| Other costs (1000 yuan ha$^{-1}$)             | 0       | 0           | 7975    | 31 700.1    | 85 760.9|
| Fine management (labor input) (days ha$^{-1}$)| 0       | 52.5        | 112.5   | 202.5       | 742.5   |
| Fine management (%)                           | 0       | 0.41        | 0.57    | 0.71        | 0.92    |
| Average quantity of trees (number ha$^{-1}$)  | 395.2   | 600         | 825     | 1050        | 2145.1  |
| Average age of trees (years)                  | 1.13    | 5           | 7       | 10          | 21      |
| Eastern provinces (dummy)                     | 0       | 0           | 1       | 1           | 1       |
| West provinces (dummy)                        | 0       | 0           | 0       | 1           | 1       |

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