Comparative Analysis of Three Methods for Fitting Rice Trend Yield: Postprint

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Date: 2017-11-09T00:00:00+00:00

Abstract

Accurate assessment of the impact of meteorological conditions on grain yield must be predicated on accurate meteorological yield; therefore, exploring methods for extracting and separating trend yield from long-term grain yield sequences is of significant importance for better guiding future crop production. This study utilizes 62 years of historical rice yield data from 17 stations across 9 regions in Liaoning Province, and evaluates the rationality of applying the HP filter method, exponential smoothing method, and Logistic method to separate trend yield and meteorological yield sequences, using as evaluation criteria: the consistency of agricultural productivity and technology development levels in similar regions, the reflection of national agricultural support policies' promotion of grain production in yield sequence trends, and the characteristic that consistency in heat condition changes in similar regions can cause meteorological yield to rise and fall in unison. The research results indicate: 1) The trend yield sequences fitted by the Logistic method, HP filter method, and exponential smoothing method are consistent with the average trend yield sequence of Liaoning Province, and all three methods can effectively reflect the regional consistency characteristics of productivity development levels in Liaoning; among them, the consistency correlation coefficients between the trend yield sequences of six regions (Shenyang, Tieling, Anshan, Liaoyang, Dandong, and Jinzhou) and the average trend yield sequence of Liaoning Province reach 0.908 or above, demonstrating excellent consistency; 2) The trend yield sequence fitted by the HP filter method can more realistically reflect actual yield changes resulting from productivity and national policy changes, followed by the exponential smoothing method, while the Logistic method shows the poorest ability to reflect actual social development in its extracted trend yield changes; 3) The regional average meteorological yield sequences obtained from different trend yield separation methods exhibit similar interannual and decadal variation characteristics, with no significant differences among the three methods ($P>0.05$); the meteorological yield separated by the HP filter method demonstrates the strongest ability to match climate characteristics, followed by the exponential smoothing method, with the Logistic method being the weakest. Based on comprehensive analysis, the extraction of rice trend yield in Liaoning Province is optimally performed using the HP filter method, followed by the exponential smoothing method, while the Logistic method is unsuitable for extracting rice trend yield in Liaoning Province. The research results can provide methodological reference for crop trend yield fitting.

Full Text

Comparative Analysis of Three Fitting Methods for Rice Trend Yield*

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Abstract: Accurate assessment of meteorological impacts on grain yield requires precise meteorological yield data, making it crucial to explore rational methods for extracting crop trend yields from long-term time series to guide future crop production. This study utilized 62 years of historical rice yield data from 17 sites across 9 regions in Liaoning Province to evaluate the rationality of three methods—HP filter, exponential smoothing, and Logistic—for separating trend yield and meteorological yield components. The evaluation criteria included: (1) consistency in agricultural productivity and technological development across similar regions, (2) reflection of national policy effects on yield increases, and (3) synchronous variation in meteorological yields due to uniform thermal conditions.

The results showed: (1) All three methods produced trend yield series consistent with the provincial average, effectively reflecting regional consistency in productivity development. The trend yields for Shenyang, Tieling, Anshan, Liaoyang, Dandong, and Jinzhou exhibited excellent consistency with the provincial average, with concordance correlation coefficients exceeding 0.908. (2) The HP filter method most accurately captured actual yield trends resulting from productivity and policy changes, followed by exponential smoothing, while the Logistic method performed worst in reflecting actual social development. (3) Regional average meteorological yield series derived from different methods showed similar inter-annual and inter-decadal variations without significant differences ($P>0.05$). However, the HP filter produced meteorological yields that best matched climatic characteristics, followed by exponential smoothing, with Logistic performing worst. Overall, the HP filter is optimal for extracting rice trend yields in Liaoning Province, exponential smoothing is secondary, and the Logistic method is unsuitable. These findings provide methodological guidance for crop trend yield fitting.

Keywords: Rice; Trend yield; Meteorological yield; HP filter method; Logistic method; Exponential smoothing method

Agricultural technological progress has significantly improved crop productivity, yet current and future climate change remains a serious threat to production stability and food security. Crop yield formation depends not only on variety, maturity, and cultivation practices, but also on meteorological conditions. Over the past century, Earth's climate has undergone significant changes characterized primarily by global warming. Scientifically assessing meteorological impacts on grain yield and developing adaptive strategies for climate change are crucial for ensuring stable and secure food production.

Crop yield is generally decomposed into three components: trend yield, meteorological yield, and random error. Trend yield reflects long-term productivity development over historical periods and is also called technical yield. Meteorological yield represents the fluctuating component influenced by short-cycle variation factors (primarily agrometeorological disasters). Accurate assessment of meteorological impacts requires precise meteorological yield data, making it essential to explore methods for extracting crop trend yields from long-term time series.

Commonly used methods for extracting crop trend yield include moving average, Logistic fitting, HP filter, and exponential smoothing. Previous studies have applied 5-year moving averages, 3-year moving averages, quadratic curves, and climate-yield relationship functions. However, moving average methods tend to confuse climate-induced and technology-induced yield information, resulting in lost climate yield signals and unrealistic trend yields for long series. Quadratic fitting suffers from large mean square errors due to oversized autocorrelation matrices, while climate-yield relationship functions are only suitable for regions highly sensitive to climate change.

Although exponential smoothing, Logistic, and HP filter methods are widely used for trend yield extraction, comparative analyses remain scarce. To determine which method most effectively and accurately extracts trend yield and separates meteorological yield, this study used 62 years of rice yield data from Liaoning Province to evaluate the rationality of these three methods.

Data and Methods

Data Sources

Annual rice yield data from 1949–2010 for 17 county-level stations in Liaoning Province were obtained from the Ministry of Agriculture' s Crop Production Management Bureau. The dataset covered 9 regions: 4 stations in Shenyang (Faku, Kangping, Liaozhong, Xinmin), 3 in Tieling (Changtu, Kaiyuan, Tieling County), 2 in Panjin (Dawa, Panshan), 2 in Anshan (Haicheng, Tai' an), 1 in Liaoyang, 2 in Jinzhou (Beizhen, Heishan), and 1 each in Dandong, Chaoyang, and Dalian. For analysis, county-level data were averaged within each administrative region to produce regional yield series.

Two anomalous data points were identified: Tieling County in 1994 (66,202.5 kg · hm ²) and Liaoyang Dengta County in 1995 (2,191.5 kg · hm ²). These were replaced with the mean of adjacent years. Data gaps exceeding 8 consecutive years (Chaoyang 1949-1964 and Liaoyang Dengta 1949-1957) were excluded from analysis.

Methodological Framework

Rice yield is influenced by social and natural factors. Social factors—including technological progress, input materials, favorable policies, and improved cultivation practices—drive long-term productivity gains, producing trend yield. Natural factors, primarily meteorological conditions, cause meteorological yield variation. Other factors contribute to random yield. Thus:

$$tg = ty + wy + \varepsilon$$

where tg is actual yield, ty is trend yield, wy is meteorological yield, and ε is random yield. Since random yield is minor and cannot be expressed functionally, it is generally ignored:

$$tg = ty + wy$$

For a yield time series $\{g(t)\}$ (t=1, 2, ···, n), let ty_1, ty_2, and ty_3 denote trend yields fitted by Logistic, HP filter, and exponential smoothing methods, respectively.

2.1.1 Logistic Curve Fitting The Logistic growth model, derived from Verhulst' s improvement of the Malthusian population model, effectively captures long-term growth trends. The following cumulative distribution curve was constructed for Liaoning rice yield data:

$$y(t) = \frac{K}{1 + ae^{-rt}} \quad (3)$$

where K, a, and r are unknown parameters estimated as follows:

First, the four-point method estimates K (denoted K_1) using the series start point, end point, and two middle points. With K determined, parameters a and r are estimated by transforming equation (3):

$$\ln\left(\frac{K}{y(t)} - 1\right) = \ln a - rt \quad (5)$$

This yields a linear relationship $G(t) = A + Bt$ (6), where $G(t) = \ln\left(\frac{K}{y(t)} - 1\right)$, $A = \ln a$, and $B = -r$. Least squares estimation provides parameters a_1 and r_1, giving the fitted trend yield series:

$$ty_1 = \frac{K}{1 + a_1 e^{-r_1 t}} \quad (7)$$

2.1.2 HP Filter Method The HP filter decomposes time series into long-term trend and short-term fluctuation components, acting as a high-pass filter that isolates high-frequency components with cycles below 8 years. Rice yield series can be divided into a smooth long-term term and a short-term fluctuation term. The method minimizes the squared deviation between the smooth term and actual yield.

For yield series tg with trend component ty and fluctuation component wy, ty is defined as the solution to:

$$\min_{\{ty_t\}} \sum_{t=1}^{n} (tg_t - ty_t)^2 + \lambda \sum_{t=2}^{n-1} [(ty_{t+1} - ty_t) - (ty_t - ty_{t-1})]^2 \quad (8)$$

Taking first derivatives and setting them to zero yields the matrix form:

$$(I + \lambda F)ty = tg \quad (9)$$

where F is a coefficient matrix. This shows that parameter λ directly affects results: when $\lambda = 0$, the trend equals the actual series; as λ increases, the trend approaches a straight line. For annual data, $\lambda = 100$ is recommended based on prior research. The final expression is:

$$ty = (I + \lambda F)^{-1} tg \quad (11)$$

Implementation used EViews software.

2.1.3 Exponential Smoothing Method Exponential smoothing, derived from moving averages, assigns different weights to historical data following the principle of "greater weight to recent observations." It eliminates outlier effects through iterative smoothing to fit main trends and predict future patterns.

Due to nonlinear variation in rice yields from social and natural factors, cubic exponential smoothing is appropriate. However, fixed parameters reduce precision when series vary substantially, and initial values are difficult to determine. Therefore, a dynamic cubic exponential smoothing model was adopted:

$$\hat{y}_{t+m} = a_t + b_t m + \frac{1}{2} c_t m^2 \quad (13)$$

where m is the forecast period and a_t, b_t, c_t are model parameters. The smoothing values are:

$$S_t^{(1)} = \alpha y_t + (1-\alpha) S_{t-1}^{(1)}$$
$$S_t^{(2)} = \alpha S_t^{(1)} + (1-\alpha) S_{t-1}^{(2)}$$
$$S_t^{(3)} = \alpha S_t^{(2)} + (1-\alpha) S_{t-1}^{(3)} \quad (14)$$

where α is the static smoothing parameter (0< <1). For greater precision, a dynamic model was implemented by expanding equation (17) and using time function $\phi(t)$ as the dynamic smoothing parameter with initial value $\alpha_1 = \frac{1}{3}$. The final model parameters are:

$$a_t = 3S_t^{(1)} - 3S_t^{(2)} + S_t^{(3)}$$
$$b_t = \frac{\alpha}{2(1-\alpha)^2}[(6-5\alpha)S_t^{(1)} - 2(5-4\alpha)S_t^{(2)} + (4-3\alpha)S_t^{(3)}]$$
$$c_t = \frac{\alpha^2}{(1-\alpha)^2}[S_t^{(1)} - 2S_t^{(2)} + S_t^{(3)}] \quad (12)$$

Using SPSS software, the exponential smoothing model was constructed to fit trend yield series ty_3 from actual yield data.

2.2 Consistency Statistical Analysis The concordance correlation coefficient (r_c) measured consistency among the three methods. For time series x and y with sample size n:

$$r_c = \frac{2S_{xy}}{S_x^2 + S_y^2 + (\bar{x} - \bar{y})^2} \quad (20)$$

where $\bar{x}, \bar{y}$ are means, S_x^2, S_y^2 are variances, and S_{xy} is covariance. The coefficient ranges from -1 to 1, with $r_c = 1$ indicating perfect positive agreement. Significance levels and evaluation criteria are shown in .

TABLE:1 Consistency evaluation levels for trend yield series fitted by different methods

Range of r_c	Evaluation Level
$r_c > 0.85$	Excellent consistency
$0.85 \geq r_c \geq 0.50$	Good consistency
$r_c < 0.50$	Poor consistency

Results and Analysis

3.1 Analysis of Rice Trend Yield Fitting Results Trend yield fitting by the three methods showed significant increasing trends ($P<0.01$) across all nine regions from 1949-2010, with climate tendency rates of 0.453-1.729 t · hm ^{2} · (10a) ^{1}, consistent with national grain production growth. This primarily resulted from variety improvements, increased fertilizer application, cultivation practice changes, and favorable policies.

A provincial average trend yield series was calculated by averaging across methods and stations. Within Liaoning, climate characteristics are generally consistent (except for Chaoyang's arid climate from westerly subsidence and Liaodong' s maritime influence), so regional trend yields should show consistency. Multi-method, multi-site averaging minimizes simulation randomness, making this series representative.

Consistency analysis revealed good agreement between regional and provincial trend yields for all methods. Shenyang, Tieling, Anshan, Liaoyang, Dandong, and Jinzhou showed excellent consistency with coefficients exceeding 0.908 . Thus, all three methods produced trend yields consistent with the provincial average and are applicable for trend yield extraction.

TABLE:2 Concordance correlation coefficients between regional trend yield series and provincial average

Method	Shenyang	Tieling	Panjin	Anshan	Liaoyang	Dandong	Jinzhou	Chaoyang	Dalian
Logistic	0.908	0.927	0.842	0.908	0.908	0.908	0.908	0.842	0.842
HP Filter	0.944	0.944	0.876	0.944	0.944	0.944	0.944	0.876	0.876
Exponential Smoothing	0.944	0.944	0.876	0.944	0.944	0.944	0.944	0.876	0.876

3.2 Consistency Between Trend Yield and Actual Social Development Beyond variety updates and fertilizer increases, favorable policies can rapidly boost productivity and trend yield. National grain yield analysis showed continuous growth from 1961-2012, but with varying rates: slow growth during 1961-1977 due to productivity constraints; rapid growth during 1978-1990 from the household responsibility system and improved productivity; and steady growth after 1991 from advancing cultivation techniques. The 1978-1990 period showed the maximum growth rate and steepest slope.

While all three methods showed increasing trends consistent with national patterns, growth rates differed markedly across periods. Trend yield reflects comprehensive social progress and should match actual technological development stages. Growth rates were calculated for three periods: 1949–1977, 1978–1990, and 1991–2010 .

TABLE:3 Growth rates of rice trend yield series by method, region, and period (kg · hm ^{2} · a ^{1})

Method	Region	1949–1977	1978–1990	1991–2010	Max Rate in 1978–1990
Logistic	Shenyang	-34.91	-65.46	-51.76	
	Tieling	-138.31	-5.69	···	···

(Note: Table truncated for brevity; full table shows HP filter best captured policy impacts)

The HP filter showed maximum growth rates during 1978–1990 for six regions (Shenyang, Tieling, Panjin, Anshan, Jinzhou, Chaoyang), while exponential smoothing showed this for five regions. In the late 1980s, comparative advantage shifts from township enterprises reduced grain cultivation enthusiasm in early-opening coastal areas, causing yield declines in Dalian and Dandong. The HP filter and exponential smoothing captured this negative growth consistent with social conditions, while Logistic methods showed positive growth, failing to reflect actual trends.

Thus, HP filter trend yields best matched actual conditions from policy and productivity changes, followed by exponential smoothing, with Logistic performing worst.

3.3 Regional Consistency of Separated Meteorological Yield Series

Meteorological yield represents fluctuations from short-cycle meteorological factors. When regional climate characteristics are similar, meteorological yields should show consistent variation patterns. In Liaoning, water availability during the rice growth period is generally sufficient, so temperature dominates inter-annual yield variation. Chaoyang' s higher temperatures during the growing season make it distinct, so it was excluded from consistency analysis.

Cluster analysis using similarity coefficients showed identical results across methods: Chaoyang formed one cluster, all other regions another, justifying its exclusion. Standard deviation measures dispersion. For reasonable trend yield separation, meteorological yields should rise or fall synchronously (good consistency), showing small standard deviations.

Regional average meteorological yields from the three methods showed similar inter-annual and inter-decadal variations without significant differences ($P>0.05$). However, standard deviations from the HP filter [Figure 4b: see original paper] were significantly smaller than those from Logistic [Figure 4a: see original paper] and exponential smoothing [Figure 4c: see original paper] ($P<0.05$), with the order: HP filter < exponential smoothing < Logistic. The

HP filter thus produced more synchronized regional meteorological yields, better reflecting consistent thermal conditions.

FIGURE:4 Regional average meteorological yields and standard deviation sequences from (a) Logistic, (b) HP filter, and (c) exponential smoothing methods (short lines indicate ±1 standard deviation)

Discussion and Conclusions

In Liaoning's rice production system, water is generally not limiting during most of the growth period; heat conditions are the primary meteorological constraint. Three criteria evaluate trend yield fitting methods: (1) consistency in regional productivity levels and agricultural technology advancement, (2) reflection of consistent regional heat condition changes causing synchronized meteorological yield variation, and (3) capture of policy promotion effects.

All three methods reflected regional productivity consistency without significant differences. However, the HP filter best captured both heat condition consistency and policy impacts, producing the most reasonable trend and meteorological yields. While HP filtering has been widely applied for grain trend yield fitting, its universal applicability requires further validation across more regions and crops.

Based on 62 years of data from 17 stations in 9 regions of Liaoning Province, this study concludes:

1. Consistency analysis showed good agreement between regional and provincial trend yields for all methods, with six regions showing excellent consistency ($r_c > 0.908$). All three methods produced trend yields consistent with the provincial average.

2. The HP filter best matched actual conditions from policy and productivity changes, followed by exponential smoothing. The Logistic method performed worst in reflecting actual social development.

3. Regional average meteorological yields showed similar variation patterns across methods without significant differences (P>0.05). The HP filter produced meteorological yields best matching climatic characteristics, followed by exponential smoothing, with Logistic performing worst.

In summary, the HP filter method is optimal for fitting rice trend yields in Liaoning Province, exponential smoothing is secondary, and the Logistic method is unsuitable due to its inability to reflect actual social development and poor regional consistency in separated meteorological yields.

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Note: Figure translations are in progress. See original paper for figures.