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环境博士文库

# 水稻生产优化管理模拟系统研究

# STUDIES ON SIMULATION SYSTEM FOR OPTIMUM MANAGEMENT IN RICE PRODUCTION

严力蛟 著

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# 摘 要

作物生长发育的动态模拟研究始于 20 世纪 60 年代，是随着系统分析方法和计算机技术在作物科学中的应用而兴起的。作物生长发育的动态模拟是指将作物及其气象和土壤等环境作为一个整体，应用系统分析的原理和方法，综合大量的作物生理学、生态学、农学、农业气象学、土壤肥料学等学科的理论和研究成果，对作物的生长发育、光合生产、器官建成和产量形成等生理过程及其与环境和技术的关系加以理论概括和数量分析，建立相应的数学模型，然后在计算机上进行动态的定量化分析和作物生长过程的模拟研究。

本书在查阅了国内外水稻生长发育动态模拟研究领域大量文献和田间试验的基础上，组建了水稻生产优化管理模拟系统（Simulation System for Optimum Management in Rice Production，SSOMRP）。该系统包括三个子模型或子系统，即水稻生长发育模拟模型（Simulation Model of Rice Growth and Development，SMRGD）、水稻氮肥优化管理模拟系统（Simulation System for Optimum Fertilizer-N Management in Rice Production，SSOFMRP）和水稻生产水分管理模拟系统（Simulation System for Water Management in Rice Production，SSWMRP）。

## 1 不同施氮水平与水分管理方式对水稻生长的影响

本试验于 1997 年在浙江省绍兴市农业学校实验农场进行。试验以粳稻品种玉占为材料，通过不同施氮水平的大田试验及不同水分管理方式的盆栽试验，研究不同水平施氮量和不同水分管理方式对水稻的生育特性及产量的影响。

### 1.1 不同施氮水平

氮肥试验设 7 个处理，每公顷施用纯氮分别为：L1，0kg；L2，97.5kg；L3，120kg；L4，142.5kg；L5，165kg；L6，187.5kg；L7，210kg。结果表明，其分蘖数与施氮量呈显著正相关，$R^2$=0.9456**，分蘖数与产量呈显著二次抛物线关系，$y=-146.46x^2+3794.7x-17845$，$R^2$=0.9146**。可见当施氮量从 0kg 逐渐增加时，分蘖数和产量随之增加；当施氮量达到一定水平，分蘖数继续增加而产量下降。施氮量与植株含氮量呈显著线性关系，其施氮量与叶小样、茎小样的氮含量的相关系数分别为 $R_{叶}$=0.9590**和 $R_{茎}$=0.9666**。根据株高、穗长、每穗实粒数、每穗总粒数、结实率、每穗秕粒数与施肥量之间的关系，可以推断，在当地条件下，其最佳施肥量是 120kg/$hm^2$ 左右。

### 1.2 不同水分管理

通过对 5 种水分管理方式（常规法、淹灌法、湿润法、间歇法、半旱法）的比较试验，发现从生育期和高产两方面考虑，湿润法要优于其它几种方法；但其穗粒蛋白质含量低，即品质较劣。间歇法也有高产低质的趋势。常规法可获得较高品质的穗粒且生产周期较短，但产量不高。半旱法亦是高质低产，且生产周期长。而淹灌法则各项指标均居中。可见各种水分管理方式各有优劣，应该根据生产实际需要选择合适的方法。同时获得短周期、优质高产的方法还有待进一步探索。

## 2 水稻生长发育模拟模型

本研究在 F.W.T. Penning de Vries 等研制的解释性模型 L1D 和 TIL 的基础上，通过田间试验和文献资料的收集，组建了水稻生长发育模拟模型。该模型包括下列 7 个子模型：光合作用子模型、呼吸作用子模型、同化物分配子模型、干物质形成子模型、光合面

积消长子模型、分蘖（包括主茎）动态子模型、生育期进程子模型。

利用该模型实时模拟了生育天数、茎干重、叶干重、穗干重、地上部干重、叶面积系数和分蘖数，并与实测值相比较，相关性（$R^2$）分别为 0.9992、0.9703、0.8974、0.9885、0.993、0.8644、0.9001，均达到极显著水平。利用嘉兴 1990 年的气象资料和粳稻品种秀水 620 对移栽期、秧龄和基本苗的最佳组合进行了模拟和优化。得出模拟产量最高值（13545 $kg/hm^2$）的最佳移栽期、秧龄和基本苗分别为 7 月 15 日、41d 和 $0.40 \times 10^6$ 本/$hm^2$。

## 3 水稻氮肥优化管理模拟系统

本研究以氮行为模型 ORYZA-0 为基础模型，组建了水稻氮肥优化管理模拟系统。该系统包括 5 个子模型，即干物质积累子模型、植株中氮素的运转和分配子模型、植株对氮的吸收速率子模型、氮肥吸收率子模型、氮肥施用曲线子模型。

在浙江省金华市郊区，杂交晚稻汕优 46 各生育阶段植株的含氮量和氮吸收的动态模拟结果为：（1）植株总吸氮量随施氮量的增加而增加，但在高氮（施氮量高于 210$kg/hm^2$）处理下，其增加幅度明显低于中、低氮处理；（2）吸氮速度生育前期较快，而生育后期逐渐减慢；（3）叶片含氮量在初花期前随生育天数的增加而迅速增加，但在初花期以后逐渐下降。不同施氮水平下，干物质积累量和经济产量的模拟值与实测值吻合得较为理想。

将水稻氮肥优化管理模拟系统与 Price 优化程序结合，求得在浙江省金华市郊区生态条件下，杂交晚稻汕优 46 最佳的施肥量和施肥时间为：（1）在低氮处理水平（50～100 $kg/hm^2$）下，最佳的氮肥管理策略是所有氮肥集中在栽移后 25d（幼穗分化期）前施下；（2）随施氮水平提高，后期施氮比重增加，但 90%～100%的氮肥应在移栽后 40d（约开花期前一周）前施下；（3）当施氮量超过一阈值（如 210 $kg/hm^2$），在高氮水平下各处理采取类似的氮运筹方法。

1994 年和 1995 年（地点为浙江省金华市郊区，品种为协优 46）

的验证结果表明，在节氮 30 kg/hm$^2$ 的条件下，两种模拟优化方案（T4: 150 kg/hm$^2$，分别于移栽后 8d、19d、27d、38d，分 4 次等量施入；T5: 150 kg/hm$^2$，分别于移栽后 0d、8d、27d、40d，分 4 次按 0.55: 0.15: 0.2: 0.1 比例施入）比当地常规施氮处理（T2: 180 kg/hm$^2$，分别于移栽后 0d、5d、25d，分 3 次施入，用量比例为 0.65: 0.15: 0.20），分别增产 6.03%~6.87%和 8.58%~11.08%，主要表现在总粒数和实粒数明显增加。1996 年在金华市郊区实施的大田示范性试验，同样表现为比常规法增产，其增产幅度达到 14.80%。

1999 年分别在气候和土壤条件各异的浙江省新昌县、金华县和慈溪市进行适应性试验。结果表明，总施氮量模拟区均低于常规区，减少幅度为 2.18%~4.53%；实测产量在新昌县、金华县和慈溪市三个点模拟区比常规区增产，其增产幅度分别达到 56.12%、7.42%和 9.49%；另外，新昌、金华和慈溪三个点模拟区与常规区比较，均表现出增效，增收节本金额分别达到 3324.27 元/hm$^2$、831.25 元/hm$^2$ 和 548.65 元/hm$^2$。

## 4 水稻生产水分管理模拟系统

水稻生产水分管理模拟系统是在 ORYZA-W 基础上组建的，它包括两个子模型：水稻生长发育模型和土壤水分平衡模型。水稻生长发育模型是在原有的水稻生长发育模型 ORYZA1 的基础上加入了水稻根系生长、水稻蒸发蒸腾速率、水分胁迫与水稻生长发育的关系。土壤水分平衡模型则考虑了各种水分输入和输出过程与水稻根区含水量之间的关系。

利用该系统模拟了水稻田中表层水深度，并与实测值比较，模拟值与实测值吻合。最后，运用该系统模拟了不同表层水深度和水分管理模式下的水稻产量，模拟结果表明，最适表层水深度为 9cm，最佳水分管理模式为变化灌溉。

迄今为止，水稻优化管理模拟系统的研究和应用在建模方法、参数确定和生产应用等 3 个方面尚存在一些问题，有待进一步研究。

作者认为：进一步研制和完善包括营养元素、病虫草害在内的，以作物生理生态为基础的水稻生产综合模拟系统，充分利用以信息技术为主体的现代科学技术，组织全国范围的协作试验以建立水稻品种参数数据库和研制估算水稻品种参数的数学方法，将水稻生产优化管理模拟系统与 3S 技术和专家系统结合，组建基于 3S 技术的水稻生产优化管理决策支持系统，是提高水稻生产优化管理系统实用性的关键。

**关键词**：水稻生产；模拟系统；优化管理

# Abstract

Studies on dynamic simulation of crop growth processes began in 1960s along with the application of system analysis methodology and computer technology in agriculture. Crop simulation is referred to a set of technological systems that integrate crop-climate-soil systems as a whole, apply the principles and methods of system analysis, draw on knowledge from disciplines such as crop physiology, ecology, agronomy, meteorology and soil science, analyze qualitatively and quantitatively the physiological processes, such as crop growth, development, photosynthesis, apparatus building and yield formation, environments and technology, and their relationships, set up mathematic models, and simulate the processes of crop growth by running the models in the computer.

Based on the results of field trials and the reviews on the publications of previous studies, the author set up a Simulation System for Optimum Management in Rice Production (SSOMRP), which included three sub-models or sub-systems, namely Simulation System for Optimum Fertilizer-N Management in Rice Production (SSOFMRP), Simulation Model of Rice Growth and Development (SMRGD) and Simulation System for Optimum Water Management in Rice Production (SSOWMRP).

**1 Effects on Rice Growth of Different N-applied Levels and Water Management Regimes**

The experiment was carried out in the trial farm of Shaoxing

Agricultural School in Zhejiang Province in 1997. A *japonica* cultivar, Yugu, was used as the material. The effects were studied of different applied N levels and water management regimes on rice bearing traits and yield by field trials at different applied N levels and potted trials under different water management regimes.

## 1.1 Effects of N-applied Levels

There were seven treatments of nitrogen fertilizer levels, namely L1=0kg, L2=97.5kg, L3=120kg, L4=142.5kg, L5=165kg, L6=187.5kg, L7=210kg/hm$^2$. The results were as follows: (1) significant correlation between the number of tillers and N-applied level ($R^2$=0.9456); (2) significant quadratic parabola relation between the number of tillers and yield ($y=-146.46x^2+3794.7x-17845$, $R^2=0.9146$), which indicated that the tillers and yield increased along with the increase of N-applied level, but when the N-applied level amounted to a certain level, the tillers continued to increase while the yield decreased; and (3) significant linear relation between N-applied level and content of nitrogen in the plant, and the correlation coefficients between N-applied level and content of nitrogen in leaf and stem were 0.9590 and 0.9666, respectively. The optimum N-applied level was 120 kg/hm$^2$ according to the relationships between N-applied levels and the traits such as height of plant, length of panicle, the number of fertile, infertile and total kernels per panicle, and fertility percentage.

## 1.2 Effects of Water Management Regimes

5 water management regimes were compared, which were called as general, submersion, moist, intermission and half-drought irrigation methods, respectively. The moist irrigation treatment excelled to other water management regimes for the growth duration and yield, but the content of protein in the grain was low with poor quality. The high yield

but low quality was also found in the intermission irrigation treatment. The high quality could be obtained in the general irrigation treatment, but the yield was not high because of shorter growth duration. The high quality but low yield was also found in the half-drought irrigation treatment, while the growth duration was relatively long. The test parameters were middle level in the submersion irrigation treatment. The results indicated that the different water management regimes had their positive and negative effects on different traits, and irrigation method should be adopted based on the conditions in production practice. Further studies should be carried out for the irrigation technique for the target of good quality, high yield and short growth duration.

**2 Simulation Model of Rice Growth and Development**

Based on F W T Penning de Vries's fundamental frame of L1D and TIL modules of MACROS, a dynamic simulation model of rice growth was set up according to the field trial and documental data. The model included seven sub-models, such as photosynthesis model, respiration model, assimilate partitioning model, dry matter accumulation model, leaf area growth model, tiller dynamic model and development model.

Several traits were simulated with the model, which included the growth duration, dry weight of leaf, stem, panicle, ground and underground parts, leaf area index and tillers. Simulated and observed values of these items were consistent with correlation coefficients ($R^2$) at 0.9992, 0.9703, 0.8974, 0.9885, 0.993, 0.8644 and 0.9001, respectively, and these coefficients were significant at the level at $p<0.01$. By running the model, the optimum combination of transplanting date, seedling age and the number of transplanted seedlings was July 15, 41 days and 400 000/$hm^2$, which would result in the highest yield at 13545 kg/ $hm^2$ for a *japonica* cultivar, Xiushui 620, in Jiaxing City, Zhejiang Province.

## 3 Simulation System for Optimum Fertilizer-N Management in Rice Production

A simulation system for optimum fertilizer-N management in rice production was set up based on the N-management model OYRZA-0. The system had five sub-models including dry matter accumulation model, N movement and distribution model, N uptake rate model, N uptake percentage model, and N-applied curve model.

The results of dynamic simulation on plant nitrogen content and nitrogen uptake during growth stages were as follows for a hybrid rice Shanyou 46 in Jinhua City, Zhejiang Province: (1) Total N uptake increased with the increase of N application. At high N-applied levels (more than 210 kg/hm$^2$), the increase rate of N uptake was obviously lower than those at lower N-applied treatments. (2) The N uptake rate was fast during the early stage, but the rate gradually decreased in the late stage. (3) Leaf N content increased with the increase of growing period before the pre-flowering stage, but leaf N content rapidly decreased after it. At different N-applied levels, the simulated and observed dry matter accumulation and economic yield were quite consistent.

The simulation system for optimum fertilizer-N management was applied in a combination with Price Optimum Program to identify the N response curve for obtaining the simulated biomass or economic yield at each N-applied level. The eight fertilizer-N recommendation curves corresponding to the input levels were presented. Three preliminary conclusions could be drawn from the curves. (1) At the lower N-applied levels (e.g.50 and 100 kg/hm$^2$), the best strategy was to apply almost all the fertilizer prior to 25th days after transplanting (DAT), or the panicle initiation stage. (2) At the higher N-applied levels, 90%～100% of total N should be applied before 40 DAT or the first flowering stage. (3) Similar N management strategies could be followed when total N application exceeded a threshold value (210 $kg/hm^2$).

The following was the results of validating trials in 1994 and 1995. In the condition of saving fertilizer-N 30 $kg/hm^2$, the yield levels in the optimum scheme $T_4$ (Fertilizer-N 150 $kg/hm^2$ was evenly applied on 8, 19, 27, 38 DAT, respectively) and $T_5$ (150 $kg/hm^2$ was applied on 0, 8, 27, 40 DAT, respectively at a ratio of 0.55:0.15:0.2:0.1) increased by 6.03% ~ 6.87% and 8.58% ~ 11.08%, respectively than general treatment $T_2$ (180 $kg/hm^2$ was applied on 0, 5, 25 DAT , respectively at a ratio of 0.65:0.15:0.20). The main reason was the obvious increase of total and fertile kernels per panicle. By the farm demonstration trial at the suburbs of Jinhua City in 1996, the yield in the simulated farm was 14.80% more than that in the general farm.

The farm demonstration trials were carried out in three different sites including Xinchang, Jinhua and Cixi in 1999. The total N applied in the simulated farms decreased by 2.18~4.53% than that in the general farms. The actual yield in the simulated farms increased by 56.12%, 7.42% and 9.49%, respectively in Xinchang, Jinhua and Cixi. In addition, the farmer could increase the net income at 3324.27yuan/$hm^2$, 831.25yuan/$hm^2$ and 548.65yuan/$hm^2$, respectively by using the optimum scheme.

### 4 Simulation System for Water Management in Rice Production

A simulation system for water management in rice production was set up on the basis of ORYZA-W (a rice growth model for irrigated and rain-fed environments). The system had two sub-models, namely simulation model of rice growth and a soil water balance model. On the basis of ORYZA1, the first sub-model also integrated it with root growth, potential and actual evapotranspiration and the effects of drought stress on rice growth. Soil water balance model simulated the process of water input and output in the root zone.

Simulated values of the depths of ponding water in paddy-field coincided with the observed ones. The rice yield was simulated using the model under different depths of ponding water and water management regimes. The results indicated that the optimum depth of ponding water was 9 cm, and the optimum water management regime was variable irrigation.

Finally this research addresses the problems and issues encountered in the study of simulation systems for optimum management in rice production, involving the establishment methods, parameters and applications of the system. The author proposed further researches should be conducted in the following aspects: Firstly, future systems should be set up on the basis of physiological and ecological theories, and more elements in rice production such as nutrient management, plant diseases and pest control should be included in the system; Secondly, a database of rice variety parameters should be set up by using information technology and with national cooperated field experiments. On the other hand, it is necessary to establish the technique of calculating the rice variety parameters; Thirdly, simulation systems for optimum management in rice production should be combined with 3S and expert system technologies for setting up management optimization and decision support systems, which is key to improving application of the established rice growth dynamic simulation system.

**KEY WORD:** rice; simulation system; optimum; growth and development

# 目 录