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Estimate non-linear regression models for use in growth analysis of rice (*Oryza sativa L.*)

Ebrahim Azarpour[1] , Maral Moraditochaee[2*], Hamid Reza Bozorgi[1]

[1] *Young Researchers and Elite Club, Rasht Branch, Islamic Azad University, Rasht, Iran*

[2] *Department of Agriculture, College of Agricultural Science, Takestan Branch, Islamic Azad University, Takestan, Iran*

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Abstract

Growth indices are useful for interpreting plant reaction to the environmental factors. Growth analysis is a valuable method in the quantitative analysis of crop growth, development and crop production. There are many regression models to describe the sigmoid growth patterns. By considering that, the parameters of nonlinear regression models have physiological meanings, they are preferable relation to linear regression models. The aim of this study was to collect and evaluate the high visibility non-linear regression models in the growth analysis studies of rice plant. An experiment was conducted using 3 rice cultivars (Hashemi, Ali kazemi and Khazar) in 4 nitrogen fertilizer management conditions (N1, control (no N fertilizer); N2, 30 kg N/ha; N3, 60 kg N/ha; N4, 90 kg N/ha) in randomized complete block design with 3 replications in a paddy light soil at Guilan province (Rice Research Institute, Iran, Rasht, central of Guilan and Rudsar, East of Guilan), during 2009 year. In this research all models were fitted to leaf area index (LAI), Total of dry weight (TDW) and leaf dry weight (LDW). Results indicated that all of the used models at this study described well the variation pattern of leaf area index (LAI), Total of dry weight (TDW) and leaf dry weight (LDW) by time (day after planting). And these models can be used in the growth analysis studies.

***Corresponding Author:** Maral Moraditochaee ✉ m.a4444@yahoo.com

Introduction

To more than half of humanity, rice is life itself. Life and livelihood without rice are simply unimaginable. This grain has shaped the cultures, diets, livelihoods and economies for most of Asia. Rice produces the maximum calories per unit of land among all the cereals. This feature, combined with the capacity of rice plants to withstand inundation and their ability to adapt to varied climatic and agricultural conditions, accounts for the crop's importance. China, India and Indonesia, three of the four most populous countries in the world, are the highest producers and consumers of rice. Rice ensures food security for people in many parts of the globe. This is reflected in the recent increase in rice production in Latin America and Africa, especially in the lower-income and food-deficient countries. In Europe, rice is the major crop in certain regions of Italy and Spain, and rice-based dishes are gradually substituting for other traditional dishes in Europe and the Americas, at least for some meals. Today, rice is widely consumed all around the world (Thiyagarajan and Gujja, 2013). The increase of human population and the limited availability of agricultural resources defiantly forced the search for new resources to overcome these phenomena. Developing countries face the challenges to rapidly increase agricultural productivity and feed their growing populations based on genetic potentials. Rice is one of the most important staple crops in most part of the world from which 50 to 80% of people obtain their calories (Khush, 2003). Undefined and conflicting descriptions of rice developmental stages make application of research results to farm management practices difficult. The use of time (days after emergence, days after seeding, days after flooding, days after anthesis) in lieu of developmental stage descriptions is not very meaningful for field conditions. Consequently, an objective growth staging system with enumeration adapted to the development of the plant would improve communication among scientists, farmers, and educators. We propose a rice growth staging system with four growth stages (S0 to S3: figure 1) during seedling development (unimbibed seed, radicle, coleoptile emergence from the seed, and prophyll emergence from the coleoptile), the number of vegetative stages (V1 to VF: figure 2) equal to the number of completely expanded leaves (excluding the prophyll) on the main stem, and nine reproductive growth stages (R0 to R9: figure 3) based on discrete morphological criteria (panicle initiation and differentiation, boot stage, panicle exertion, anthesis, grain expansion, grain filling, grain dry down, and grain maturity).

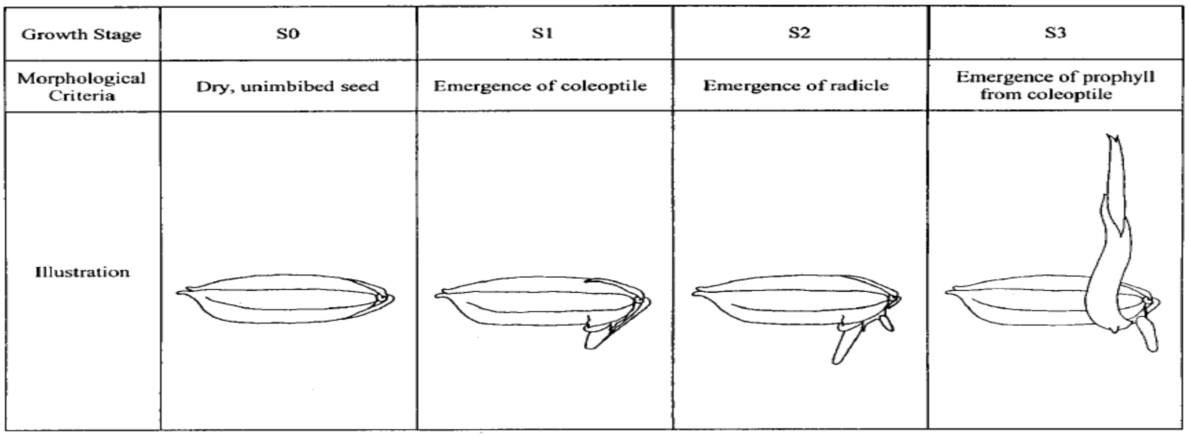


Fig. 1. Rice seedling growth stages and morphological markers

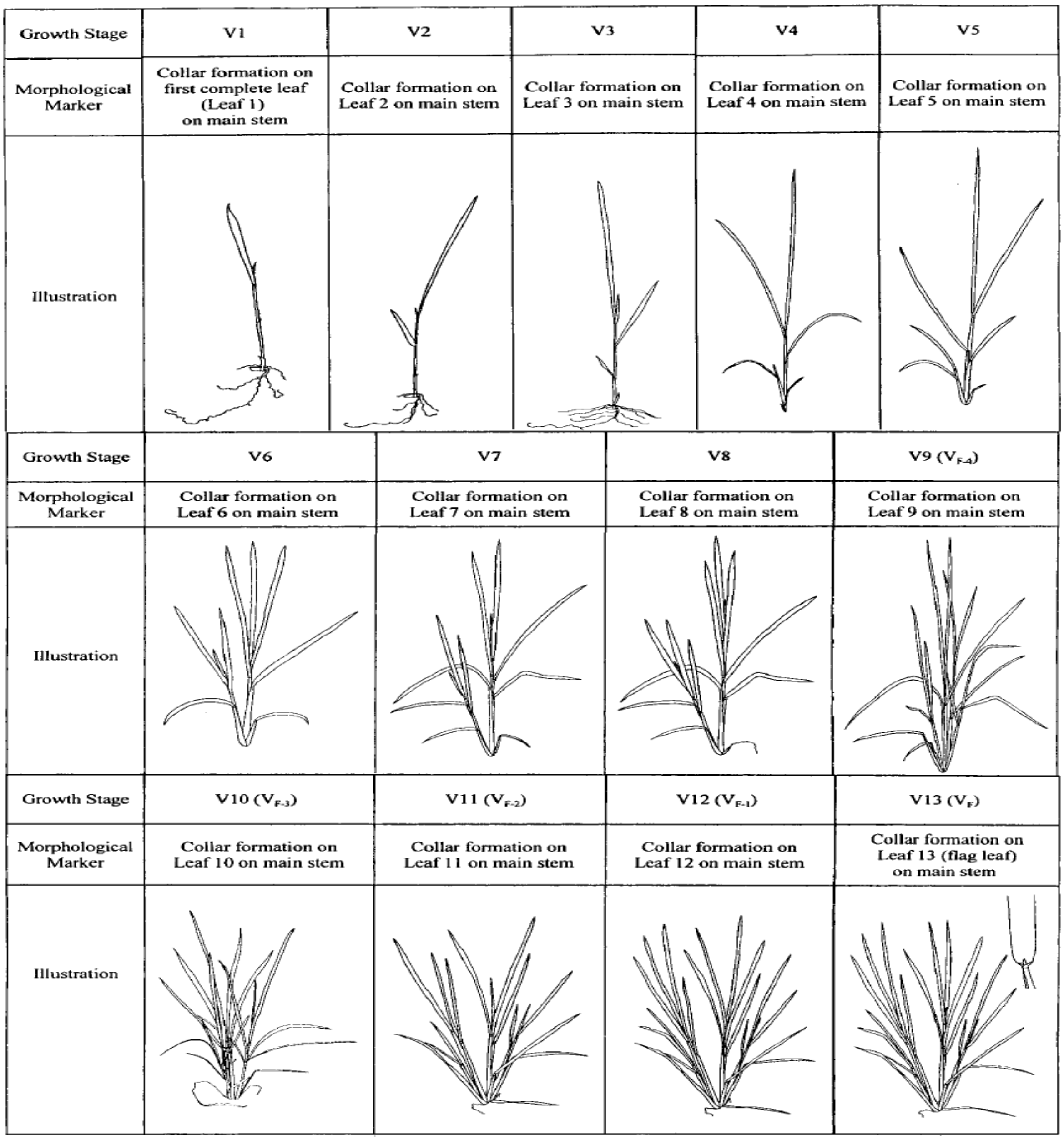


Fig. 2. Early rice vegetative growth stages and morphological markers for a rice cultivar with 13 true leaves on the main stem.

Assigning rice growth stages based on discrete morphological criteria will result in unambiguous growth stage determination (i.e., two people staging the same plant will, using this system, arrive at the same growth stage). This system takes advantage of the presence or absence of distinct morphological criteria in a framework which only permits 'yes' or 'no' answers. Consequently, an unequivocal rice growth staging system is presented which allows improved communication and application of rice research results to production practices (Counce et al., 2000).

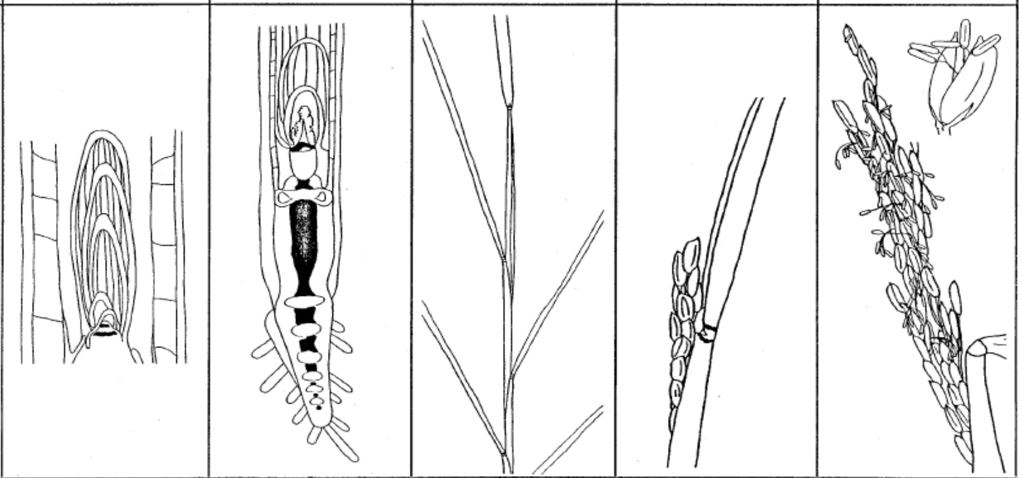
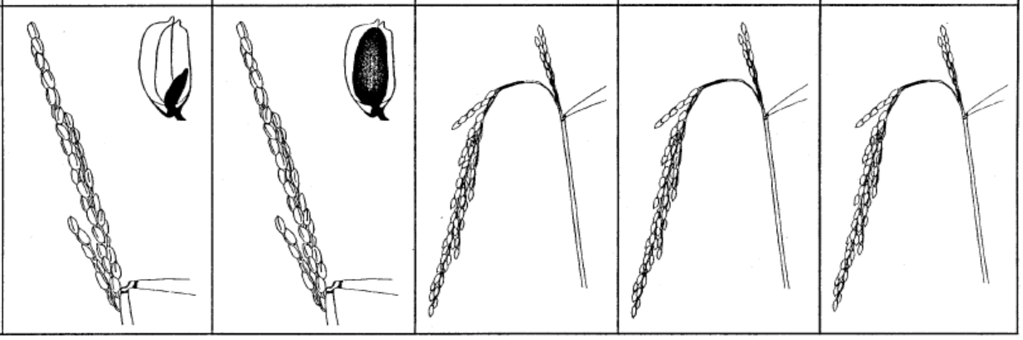
Growth Stage	R0	R1	R2	R3	R4
Morphological Marker	Panicle development has initiated	Panicle branches have formed	Flag leaf collar formation	Panicle exertion from boot, tip of panicle is above collar of flag leaf	One or more florets on the main stem panicle has reached anthesis
Illustration					
Growth Stage	**R5**	**R6**	**R7**	**R8**	**R9**
Morphological Marker	At least one caryopsis on the main stem panicle is elongating to the end of the hull	At least one caryopsis on the main stem panicle has elongated to the end of the hull	At least one grain on the main stem panicle has a yellow hull[†]	At least one grain on the main stem panicle has a brown hull[‡]	All grains which reached R6 have brown hulls
Illustration					

Fig. 3. Rice reproductive growth stages and morphological markers

Normal morphological developmental events are juxtaposed with the growth stages in Figure 4. Since some growth stages are defined by certain morphological cri- teria, they occur simultaneously (e.g., R0 and panicle differentiation, R4 and the beginning of pollination). Other events occur near the time or may not occur at all, such as elongation of the first elongating internodes. The term physiological maturity is in cluded to show when that undefined term with no criteria may occur. Seeds are certainly viable by R9 but may be viable much earlier. The grains (seeds) continue to change physically and chemically after harvest, consequently development continues after harvest, as noted on Figure 4.

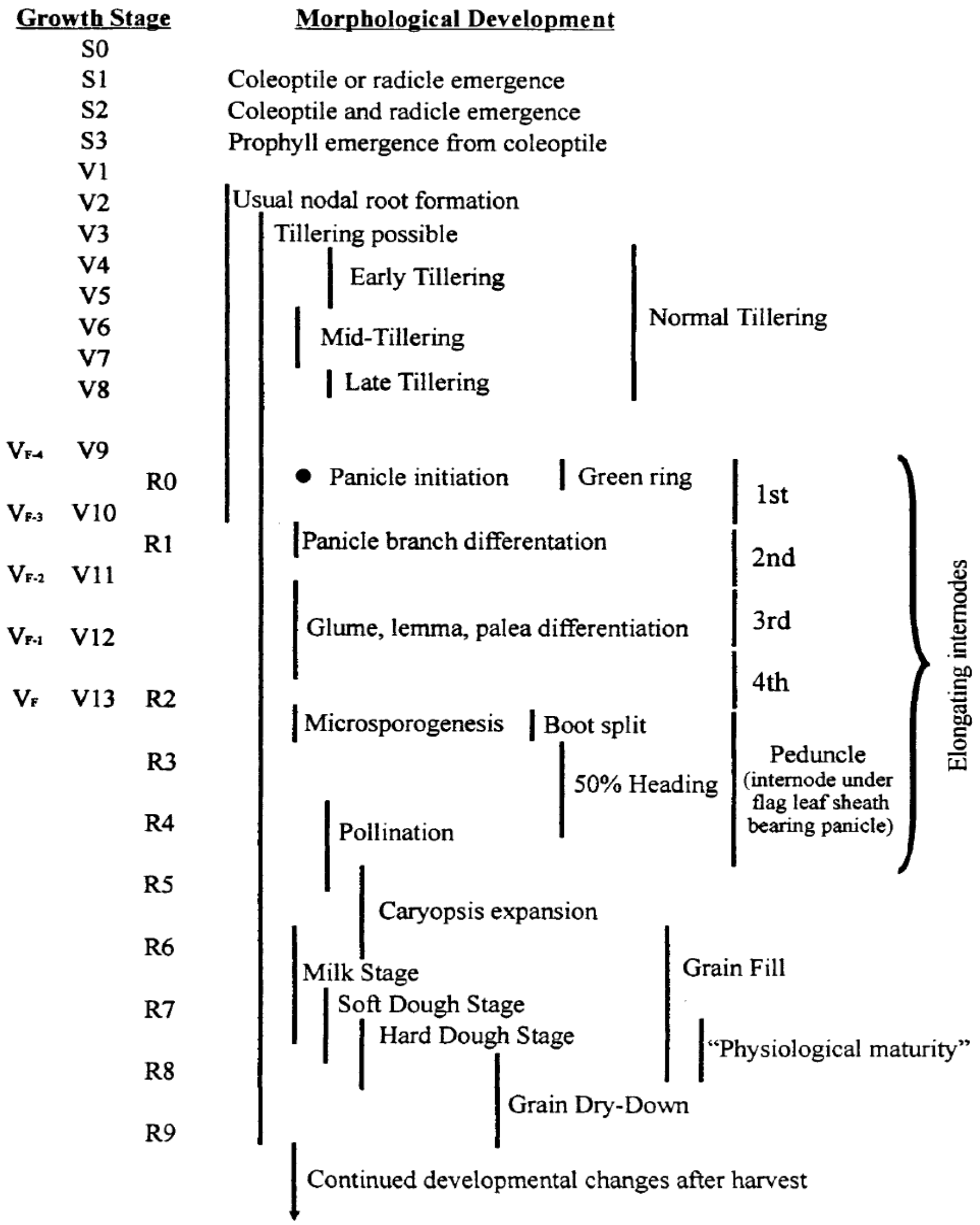


Fig. 4. Time line for rice growth stages and morphological changes in the rice plant

Most annual agricultural crops are determinate, and their growth stops once they reach physiological maturity. For indeterminate crops, growth of their individual organs is not unlimited, even when environmental conditions remain favourable. The length of the growth period and the weight of ultimate growth, either for the determinate crop as a whole or for specific organs, are two important environment- dependent traits. Crop physiologists and geneticists like to quantify the two traits to characterize genotypic variation in response to growth environments, thereby assisting breeders in the design of crop varieties for target environments. In plant simulation modelling, modellers often wish to quantify the dynamics of growth, enabling the daily growth rates being integrated to equal the expected ultimate weight at the end of the growing cycle (Read et al., 2002). A simple equation is needed to model and characterize the duration and the final weight of determinate growth processes (Yin et al., 2003). In plant growth analysis, data are usually obtained from successive destructive harvests performed within the plant growth cycle, from which the growth rates are calculated. Two main approaches have been used toward estimating growth rates: in the classical approach, mean values of growth rates are calculated by formulae previously derived, using data of two consecutive harvests, whereas in the functional approach, mathematical functions are fitted throughout the growth data over time, their differentiation providing instantaneous values of growth rates (Adelson Paulo, 2003).

Computer models can be efficiently used to simulate growth and yield of many crops since. Performances of these models depend on reliable parameterizations which require specific experiments to measure and estimate the proper crop parameters (Boschetti et al., 2006). The purpose of this experiment was to evaluated non-linear regression models for use in growth analysis of rice (Oryza sativa L.).

Materials and methods

Materials

There are many regression models to describe the sigmoid growth patterns. By considering that, the parameters of nonlinear regression models have physiological meanings, they are preferable relation to linear regression models. The aim of this study was to collect and evaluate the high visibility non-linear regression models in the growth analysis studies of rice plant. An experiment was conducted using 3 rice cultivars (Hashemi, Ali kazemi and Khazar) in 4 nitrogen fertilizer management conditions (N1, control (no N fertilizer); N2, 30 kg N/ha; N3, 60 kg N/ha; N4, 90 kg N/ha) in randomized complete block design with 3 replications in a paddy light soil at Guilan province (Rice Research Institute, Iran, Rasht, central of Guilan and Rudsar, East of Guilan), during 2009 year. Guilan Province is one of the northern provinces of Iran with an area of 14711 square meters. This province is located at 36' and 34" to 38' and 27" northern latitude and 48' and 53" to 50' and 34" eastern longitude from the Greenwich meridian.

Method to calculate growth plant indices of rice

All models were fitted to leaf area index (LAI), Total of dry weight (TDW) and leaf dry weight (LDW). Sampling of each plot was done with 15 days intervals, after removing border rows as marginal effect with selection of 4 plants, randomly. Leaf area was measured with leaf meter (GA-5 model produced by Japan OSK Company). After that different parts of rice dried in an oven at 70°C for 48 h to weight dry matter. In order to define the mathematical model which fits best to the observed data and could express the changes of LAI (Leaf Area Index), LDW (Leaf Dry Weight) and TDW (Total Dry Weight) over time regression analysis was used by MSTATC and SAS software. For this purpose data logarithm was calculated (in order to reduce further dependence of the variances to the means) and different equations were tested and the best ones based on coefficient of determination (R2) was selected. In these equations, data of leaf area, leaf dry weight and total dry weight were dependent variable and the days after sowing was an independent variable (Table 1). In this approach a polynomial of the form $Y = b_0 + b_1X + b_2X^2 + \ldots + b_nX^n$ is fitted through the growth data. The dependent variable Y is the ln-transformed weight of the plant, the independent variable X is the days of transplanting.

Table 1. Analysis of Physiological Index

Parameter	Equation	Unit
TDW	$Exp(a_1+b_1X+c_1X^{0.5}+d_1X^2+e_1X^3)$	g/m²
LAI	$Exp(a_2+b_2X+c_2X^{0.5}+d_2X^2+e_2X^3)$	-
LDW	$Exp(a_3+b_3X+c_3X^{0.5}+d_3X^2+e_3X^3)$	g/m²

Results and discussion

Plant growth analysis is an explanatory, holistic and integrative approach to interpreting plant form and function. It uses simple primary data in the form of weights, areas, volumes and contents of plant components to investigate processes within and involving the whole plant (Evans, 1972; Causton and Venus, 1981; Hunt, 1990). From its origins at the end of the nineteenth century, plant growth analysis first illuminated plant physiology, then agronomy and now physiological and evolutionary plant ecology (e.g. Garnier et al., 1999). Growth indices are useful for interpreting plant reaction to the environmental factors. Growth analysis is a valuable method in the quantitative analysis of crop growth, development and crop production. Identification of growth physiological indices in analysis of factors affecting yield and its components has a great importance and its stability determines the dry matter production which is a criterion of yield components and in this regard leaf area index (LAI), total dry weight (TDW) and leaf dry weight (LDW) should be measured in periodic intervals during the growing season (Gardner et al., 1985). Within the life cycle of an organ, a plant or a crop, the total growth duration can be divided into three sub - phases: an early accelerating phase; a linear phase; and a saturation phase for ripening (Goudriaan and van Laar, 1994). Therefore, the growth pattern typically follows a sigmoid curve, and the growth rate a bell - shaped curve. While the sigmoid pattern can be represented piecewise using an exponential, a linear and a convex equation sequentially (e.g. Lieth et al., 1996), a more elegant way is to use a curvilinear equation which gives a gradual transition from one phase to the next. In this research all models were fitted to leaf area index (LAI), Total of dry weight (TDW) and leaf dry weight (LDW) (Tables 1-3). The comparison of calculated and measured amounts of growth indexes with use determination of regression coefficients (R^2). Results indicated that all of the used models at this study described well the variation pattern of leaf area index (LAI), Total of dry weight (TDW) and leaf dry weight (LDW) by time (day after planting) ($R2 > 0.95$) (Tables 1-3). And these models can be used in the growth analysis studies.

The vegetative phase of the rice plant begins with grain germination which is signified by the emergence of the radicle or coleoptile from the germinating embryo. This is followed by the pre-tillering stage during which seminal and lateral roots and the first few leaves develop while the contents of the endosperm are absorbed by the growing seedling. The tillering stage starts with the appearance of the first tiller from the axillary bud in one of the lowermost nodes. The increase in tiller number continues as a sigmoid curve until the maximum tiller number is reached, after which some tillers die and the tiller number declines and then levels off. The visible elongation of lower internodes may begin considerably earlier than the reproductive phase or at about the same time. The reproductive phase may begin before the maximum tiller number is reached, or about the period of the highest tillering activity, or thereafter. This phase is marked by the initiation of the panicle primordium of microscopic dimensions in the main culm. Panicle development continues and the young panicle primordium becomes visible to the naked eye in a few days as a hyaline structure 1-2 mm. long with a fuzzed tip. The developing spikelets then become distinguishable. The increase in the size of the young panicle and its upward extension inside the upper leaf sheaths are detectable as a bulge in the rapidly elongating culm, often called the booting stage. When the auricles of the flag leaf are directly opposite the auricles of the next lower leaf, meiosis is usually. Occurring in the microsporocytes (pollen mother cells) and macrosporocytes of the panicle. This is followed by panicle emergence from the flag leaf sheath, commonly called heading. Anthesis or blooming begins with the protrusion of the first dehiscing anthers in the terminal spikelets on the panicle branches. Pollination and fertilization follow. The development of the fertilized egg and endosperm becomes visible a few days following fertilization. Grain development is a continuous process, but agronomic terms such as the milk stage, soft dough stage, hard dough stage, and fully ripe stage are often used to describe the different stages. As the grains ripen, the leaves become senescent and turn yellowish in an ascending order. The non-functioning leaves and culm tissues are termed dead straw. In some varieties, the culms and upper leaves may remain green when the grains are fully ripe. Under favorable growth conditions, new tillers may grow from the stubble of the harvested plants. The second and subsequent harvests from the crop are called the first and second ratoon crops, respectively (Chag et al., 1965).

Table 1. Simulated model LAI of rice cultivars under nitrogen fertilizer management

non-linear regression models	R^2
LAI_{N1V1}=Exp(-5.68226+0.39116×X-0.82925×X^0.5-0.0031825×X^2+0.0000039088×X^3)	98.5
LAI_{N2V1}=Exp(-4.989938+0.60972×X-1.7356×X^0.5-0.0059387×X^2+0.000019033×X^3)	99.3
LAI_{N3V1}=Exp(-4.897514+0.51496×X-1.3268×X^0.5-0.005115×X^2+0.000016625×X^3)	99.4
LAI_{N4V1}=Exp(-4.841257+0.53584×X-1.4045×X^0.5-0.0054088×X^2+0.000018474×X^3)	99.5
LAI_{N1V2}=Exp(-5.39189+0.68884×X-2.1002×X^0.5-0.0068325×X^2+0.000024865×X^3)	99.5
LAI_{N2V2}=Exp(-4.92429+0.63654×X-1.8253×X^0.5-0.0066634×X^2+0.000025383×X^3)	99.7
LAI_{N3V2}=Exp(-4.570545+0.61654×X-1.7504×X^0.5-0.0065574×X^2+0.000025364×X^3)	99.3
LAI_{N4V2}=Exp(-4.543057+0.5842×X-1.6054×X^0.5-0.0062057×X^2+0.000023622×X^3)	99.4
LAI_{N1V3}=Exp(-6.655732+0.27331×X-0.42428×X^0.5-0.0013179×X^2-0.0000050311×X^3)	99.4
LAI_{N2V3}=Exp(-6.628031+0.19549×X-0.0093697×X^0.5-0.00077076×X^2-0.0000067085×X^3)	99.5
LAI_{N3V3}=Exp(-6.404118+0.16764×X+0.1117×X^0.5-0.00053292×X^2-0.0000076046×X^3)	99.5
LAI_{N4V3}=Exp(-6.070909+0.20314×X-0.04586×X^0.5-0.0011351×X^2-0.0000032909×X^3)	99.8
LAI_{N1V1}=Exp (-6.274527-0.49747×X+2.8615×X^0.5+0.0066272×X^2-0.000042411×X^3)	99.9
LAI_{N2V1}=Exp (-6.245862-0.5248×X+2.995×X^0.5+0.0069805×X^2-0.000044636×X^3)	99.3
LAI_{N3V1}=Exp (-6.076604-0.55731×X+3.1212×X^0.5+0.0073988×X^2-0.000046989×X^3)	99.7
LAI_{N4V1}=Exp (-5.566069-0.44465×X+2.7097×X^0.5+0.0058649×X^2-0.000038958×X^3)	99.8
LAI_{N1V2}=Exp(-6.457382-0.49095×X+2.8709×X^0.5+0.006345×X^2-0.000040811×X^3)	99.4
LAI_{N2V2}=Exp(-6.051388-0.47952×X+2.8392×X^0.5+0.0059475×X^2-0.000037252×X^3)	99.9
LAI_{N3V2}=Exp(-5.859498-0.48301×X+2.8343×X^0.5+0.0062265×X^2-0.000039778×X^3)	99.2
LAI_{N4V2}=Exp(-5.557344-0.41791×X+2.5899×X^0.5+0.0054584×X^2-0.000036295×X^3)	99.4
LAI_{N1V3}=Exp(-6.978152-0.64768×X+3.4812×X^0.5+0.0086381×X^2-0.000052848×X^3)	99.8
LAI_{N2V3}=Exp(-6.259617-0.49169×X+2.8844×X^0.5+0.0062756×X^2-0.000038257×X^3)	99.6
LAI_{N3V3}=Exp(-6.140072-0.49194×X+2.894×X^0.5+0.0063388×X^2-0.000038711×X^3)	99.1
LAI_{N4V3}=Exp(-5.811923-0.43966×X+2.7021×X^0.5+0.0055485×X^2-0.000034121×X^3)	99.2

Table 2. Simulated model LDW of rice cultivars under nitrogen fertilizer management

non-linear regression models	R^2
LDW $_{N1V1}$=EXP(0.255330+0.40177×A1-0.79854×A1^0.5-0.004273×A1^2+0.000016058×A1^3)	99
LDW $_{N2V1}$=EXP(1.780113+0.70495×A1-2.0338×A1^0.5-0.0082948×A1^2+0.000038257×A1^3)	99.6
LDW $_{N3V1}$=EXP(1.817199+0.68894×A1-1.9529×A1^0.5-0.0082708×A1^2+0.00003943×A1^3)	99.5
LDW $_{N4V1}$=EXP(1.765316+0.44052×A1-0.90889×A1^0.5-0.005493×A1^2+0.000025681×A1^3)	99.7
LDW $_{N1V2}$=EXP(1.001507+0.45995×A1-1.0131×A1^0.5-0.0053751×A1^2+0.000023574×A1^3)	99.5
LDW $_{N2V2}$=EXP(1.562493+0.48064×A1-1.0838×A1^0.5-0.0058578×A1^2+0.000026894×A1^3)	99.8
LDW $_{N3V2}$=EXP(1.491272+0.44974×A1-0.96387×A1^0.5-0.005338×A1^2+0.000023745×A1^3)	99.6
LDW $_{N4V2}$=EXP(1.744598+0.51423×A1-1.2343×A1^0.5-0.0060912×A1^2+0.000027582×A1^3)	99.6
LDW $_{N1V3}$=EXP(-0.12909+0.27597×A1-0.26891×A1^0.5-0.0027644×A1^2+0.000009326×A1^3)	98.4
LDW $_{N2V3}$=EXP(0.473107+0.4292×A1-0.90495×A1^0.5-0.0045677×A1^2+0.00001812×A1^3))	98.9
LDW $_{N3V3}$=EXP(1.14672+0.48507×A1-1.1202×A1^0.5-0.0055874×A1^2+0.000024974×A1^3)	99.2
LDW $_{N4V3}$=EXP(1.355466+0.50981×A1-1.2286×A1^0.5-0.0057992×A1^2+0.000025372×A1^3)	99.1
LDW $_{N1V1}$=EXP(5.165606+1.4014×A1-5.7905×A1^0.5-0.014053×A1^2+0.000060601×A1^3)	96.1
LDW $_{N2V1}$=EXP(4.658808+1.1891×A1-4.8639×A1^0.5-0.011465×A1^2+0.000046969×A1^3)	97.8
LDW $_{N3V1}$=EXP(5.247845+1.3324×A1-5.4778×A1^0.5-0.013338×A1^2+0.000057896×A1^3)	97.6
LDW $_{N4V1}$=EXP(3.651343+0.7698×A1-2.8919×A1^0.5-0.0072667×A1^2+0.000028913×A1^3)	98.1
LDW $_{N1V2}$=EXP(5.515422+1.4589×A1-6.1292×A1^0.5-0.014225×A1^2+0.000059733×A1^3)	98.5
LDW $_{N2V2}$=EXP(5.143338+1.3144×A1-5.4391×A1^0.5-0.012851×A1^2+0.000054317×A1^3)	98.3
LDW $_{N3V2}$=EXP(4.822878+1.1882×A1-4.8579×A1^0.5-0.011476×A1^2+0.000047715×A1^3)	97.8
LDW $_{N4V2}$=EXP(3.526754+0.66646×A1-2.4034×A1^0.5-0.0062681×A1^2+0.00002446×A1^3)	98.8
LDW $_{N1V3}$=EXP(3.618548+0.9323×A1-3.782×A1^0.5-0.0081786×A1^2+0.000029922×A1^3)	99.2
LDW $_{N2V3}$=EXP(3.680213+0.89726×A1-3.6102×A1^0.5-0.0079052×A1^2+0.000029156×A1^3)	99.5
LDW $_{N3V3}$=EXP(3.451884+0.81011×A1-3.2330×A1^0.5-0.0067685×A1^2+0.000023096×A1^3)	99.8
LDW$_{N4V3}$=EXP(3.27726+0.69672×A1-2.6734×A1^0.5-0.0058161×A1^2+0.000019483×A1^3)	99.8

Table 3. Simulated model TDW of rice cultivars under nitrogen fertilizer management

non-linear regression models	R^2
XDW $_{N1V1}$=Exp(0.670547+0.068038×X+0.59318×X^0.5-0.00041951×X^2-0.00000050965*X^3)	98.7
XDW $_{N2V1}$=Exp(0.924649+0.12761×X+0.32921×X^0.5-0.0010261×X^2+0.0000020693*X^3)	99.7
XDW $_{N3V1}$=Exp(1.073606+0.1522×X+0.22991×X^0.5-0.0012967×X^2+0.0000032131*X^3)	99.6
XDW $_{N4V1}$=Exp(1.153976+0.14799×X+0.23946×X^0.5-0.0012136×X^2+0.0000027341*X^3)	99.8
XDW $_{N1V2}$=Exp(-0.098299-0.087928×X+1.2423×X^0.5+0.0012646×X^2-0.0000075158*X^3)	99.8
XDW $_{N2V2}$=Exp(0.372339+0.040358×X+0.68539×X^0.5+0.0000013119×X^2-0.0000024822*X^3)	99.8
XDW $_{N3V2}$=Exp(0.769167+0.15291×X+0.21042×X^0.5-0.0011748×X^2+0.0000024212*X^3)	99.7
XDW $_{N4V2}$=Exp(0.953573+0.19242×X+0.03479×X^0.5-0.0016012×X^2+0.0000041925*X^3)	99.7
XDW $_{N1V3}$=Exp(-0.000469-0.052874×X+1.1092×X^0.5+0.00071891×X^2-0.0000043354*X^3)	99.8
XDW $_{N2V3}$=Exp(0.284752+0.020438×X+0.79067×X^0.5+0.000035445×X^2-0.000001802*X^3)	99.9
XDW $_{N3V3}$=Exp(0.375838+0.042294×X+0.70911×X^0.5-0.00019833×X^2-0.0000008374*X^3)	99.5
XDW $_{N4V3}$=Exp(0.556405+0.08736×X+0.51678×X^0.5-0.00062471×X^2+0.00000076808*X^3)	99.4
XDW $_{N1V1}$=Exp(0.710822+0.16183×X+.13387×X^0.5-0.00084064×X^2-0.0000011102*X^3)	97.3
XDW $_{N2V1}$=Exp(0.890052+0.14304×X+0.21164×X^0.5-0.00067948×X^2-0.0000016031*X^3	97.3
XDW $_{N3V1}$=Exp(1.083049+0.090347×X+0.42634×X^0.5-0.00016354×X^2-0.00000375*X^3)	97
XDW $_{N4V1}$=Exp(1.25365-0.012373×X+0.89594×X^0.5+0.0006783×X^2-0.0000065629*X^3)	98.5
XDW $_{N1V2}$=Exp(0.729455+0.18403×X+0.085187×X^0.5-0.0013821×X^2+0.0000025417*X^3)	97
XDW $_{N2V2}$=Exp(0.843846+0.13852×X+0.27356×X^0.5-0.00086916×X^2+0.000000080006*X^3)	97.6
XDW $_{N3V2}$=Exp(0.933374+0.051515×X+0.60763×X^0.5+0.00019934×X^2-0.0000052581*X^3)	97.5
XDW $_{N4V2}$=Exp(1.04523+0.067853×X+0.53867×X^0.5+0.000068895×X^2-0.0000049208*X^3)	97.6
XDW $_{N1V3}$=Exp(0.269365-0.016722×X+0.91473×X^0.5+0.00069224×X^2-0.0000056402*X^3)	98.2
XDW $_{N2V3}$=Exp(0.373106-0.033581×X+0.97577×X^0.5+0.00096444×X^2-0.000007229*X^3)	98.7
XDW $_{N3V3}$=Exp(0.502731-0.021273×X+0.91109×X^0.5+0.00093983×X^2-0.0000076124*X^3)	98.3
XDW $_{N4V3}$=Exp(0.666078-0.080637×X+1.1775×X^0.5+0.0014605×X^2-0.0000096458*X^3)	99

Conclusion

Rice plant growth can be divided into three agronomic stages of development

1. Vegetative (germination to panicle initiation); 2. reproductive (panicle initiation (PI) to heading); and 3. grain filling and ripening or maturation (heading to maturity – Figure 1-3). These stages influence the three yield components: 1) number of panicles per unit land area, 2) the average number of grain produced per panicle and 3) the average weight of the individual grains. These three components determine grain yield. The purpose of this experiment was to evaluated non-linear regression models for use in growth analysis of rice (Oryza sativa L.). In this research all models were fitted to leaf area index (LAI), Total of dry weight (TDW) and leaf dry weight (LDW). Results indicated that all of the used models at this study described well the variation pattern of leaf area index (LAI), Total of dry weight (TDW) and leaf dry weight (LDW) by time (day after planting). And these models can be used in the growth analysis studies.

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