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Review Article

Targeting Productivity in Rice (*Oryza sativa L.)*

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Abstract

Recent studies on Rice focus on improving biomass partitioning and increasing photosynthetic efficiency by suppressing photo respiration and reduction of maintenance respiration in traditional C-3 rice cultivars, and inducting C-4 mechanism in new cultivars as means to maximize rice productivity where water and nutrients are not limiting. To target and achieve the set productivity in today's cultivars one should understand the relations among climate, water. nutrients and soil factors.The productivity is quantitatively determined by (1) number of panicles, (2) spikelet fertility / sterility (3) number of grains per panicle and (4) grain weight. The limits of productivity in situations posing different constraints and ways of approaching nearer to the targets are discussed.

Keywords

Rice; Productivity; Targeting; Maximization.

Introduction

Rice is the basic food for more than 50% of the world population. Although the productivity is more than doubled in the last six decades. yet it is far lower than the theoretical limits achievable for the climatic conditions where it is cultivated. To have the next break-through in productivity over and above what were contributed by Agronomists and soil Scientists, current efforts are taken care of by Physiologists geneticists and biochemists through their multi-prong research on enhancing NPP (PE, respiration and bio-synthesis) and efficient ways of diverting it to grains to improve the harvest index. Some of the soil, climate, and plant details specific to Rice (*Oryza sativa L.)* are as follows.

1. It grows in hot humid tropical / subtropical climate except in extreme cold temperate ones. Its geographic distribution ranges from 35^0S to 53^0N with temperatures varying 21^0 to 37^0C at altitudes from 0 to 2000 m. During growth period the favorable range is 26 to 30^0C and at ripening stage it is 20 to 25^0C. Below 20^0C and above 30^0C the growth is impaired. Spike sterility increaseswith the days of exposure to night temperatures below 12^0C particularly when it is continued for more than two days.

2. It is grown in widely varying soil types and land formations. It is raised in rain-fed shallow water and deep water low lands and, Irrigated and rain-fed uplands. In rice growing areas, rainfall vary from 100 t0 200cm per annum and rarely meet the water requirement of the crop that varies from 150 to 900 cm depending on soil and cultivars during the crop duration that varies from 70 to 160 days necessitating the need for irrigation in one form or the other.

3.Unlike other crops the roots are exposed to reducing conditions in the soil as Rice is grown in standing water to varying heights ranging from 15cm to 50cm and tolerates up to 2 to 3 m in submerged deep water low lands. To facilitate maintaining of standing water in the field against seepage and percolation losses puddling of soil with added green manure is done before sowing or transplanting. High water content in soil solution also demands a higher rate of application of nitrogen and potassium to main their ionic activity above critical levels for rice roots to absorb them at rates required in relation to growing conditions. The low root CEC of monocots help in the uptake of monovalent ions.

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4. Rice is an annual grass, monocot, basically a short day photoperiodicity plant, though long day and non- sensitive ones are found naturally and also introduced thru genetic improvements from time to time. Recent studies also aim at evolving cultivars without season-dependence for entering into reproductive phase.

5. Rice requirement of Silicon is high. It gives resistance to lodging and erectness to leaves thereby enhancing photosynthetic efficiency. Though lacking in direct evidence, potassium and silicon are reported to help in photosynthesis by regulating CO_2 concentration and osmotic equilibrium in leaf tissues. Such a mechanism is also reported in Tea whose requirement of potassium and silicon are much higher than other crops.

6. The floral organ is a determinate inflorescence on the terminal shoot - each plant, main plant as well as tillers carry a terminal panicle on which spikelets are arranged. Each spikelet bears a floret which when fertilized develops into a grain. Numbers of panicles per m^2, number spikelets they carry and grain weight determine the productivity. It is a self-pollinated plant with spike sterility varying between 10 and 20% with a mean around 15 %. Planting density and tillering are therefore main determinants on productivity when other factors are not limiting.

Theoretical limits of productivity with known parameters and ways and means to achieve them are discussed below.

Climate

There are many estimates available on Net Primary Production (NPP) from solar energy incident on earth surface based on photosynthetic efficiency (PE), respiration losses, and energy to biomass synthesis (19 MJ kg^{-1}biomass). Recent studies (de Lucia et al.) showed that NPP approach 200 t C ha^1 (450 t biomass ha^{-1}) and this figure is used for further discussions. Maximum productivity is also calculated from incident solar radiations using energy conversion ratios and thermodynamic limitations on the efficiencies of natural bio-cycles involved in biosynthesis (Table 1).

Table 1: Maximum productivity under unconstrained availability of resources from NPP data

Solar Radiations $MJm^{-2}d^{-1}$	Crop duration days	For the crop period						For the crop period (de Lucia et al)	
		Solar Radiation MJm^{-2}	@ Efficiency	# Biomass Kgm^{-2}	# Grain yield Kgm^{-2}	Biomass t ha^{-1}	Grain Yield t ha^{-1}	$ Biomass t ha^{-1}	$ Grain Yield t ha^{-1}
16.7	70	1169	0.104	6.40	2.56	64	26	86	34
16.7	100	1670	0.104	9.14	3,67	91	37	123	49
16.7	115	1921	0.104	10.51	4.21	105	42	142	57
16.7	120	2004	0.104	10.97	4.39	110	44	148	59
16.7	160	2672	0.104	14.67	5.85	147	59	197	79
		Mean		10.28	4.11	103	41	139	55

@ #26 % absorbed; energy conversion 4.0 assumed against maximum achievable 4.6% and 6% in C3 and C-4 Plants respectively; net efficiency - 0.26 *0.4- 0.104.

At energy to biomass synthesis - 19 MJ kg^{-1}biomass

$ *using the maximum NPP 200 C t ha^{-1} (de Lucia et al. 2014) or 450 biomass t $ha^{-1}yr^{-1b}$ (1.23 t* ha^{-1}biomass per day)

Maximum grain productivity lies around a mean of 48 t ha^{-1} ranging from 26 to 79 t ha^{-1} for crop duration of 70 to 160 days Thus there is a large gap of unexploited potential challenging the geneticist physiologist and bio –chemist to achieve it through improving harvest index. Harvest index is around 35 to 45 % on total biomass including root mass and 45 to 60% on the biomass of the above ground parts i.e., of straw and grain. Absolute harvest index of 40% is used in thediscussions. Mean partitioning of dry matter from various reports available is 20:40:40 for root, straw and grain respectively.

Plant Factors

The ultimate grain productivity is determined by panicles per unit area, spikelets per panicle and grain weight. Most commonly used productivity equation is given below:

Grain t ha^{-1} = Panicles m^2 x Spikelets per paniclex 1000 grain weight in g x 10^{-5}

Since Panicle is the determinate terminal inflorescence, panicle number is the same as number of plants (main plant +tillers) bearing panicles. Hence number of plants planted per hill at the time of transplanting or the seed rate for direct sowing and tillering capacity of the cultivar influence the productivity. In resources deficient systems, where components have different degrees of deficiency level, the interactions among these factors are complex and difficult to predict as lot of compromises in plant’s

Table 2: Ultimate determinants of productivity

Panicles m^2	*Spikelets Per panicle*	*Grain weighting*	Fertility	Grain yield t ha^{-1}	Details	Area per plant-(panicle) cm^2
400	100	0.025	1.00	10.0	*IR 72	25
600	100	0.025	1.00	15.0	*IR 72	17
700	100	0.025	0.80	14.0	Amaroo* japan	14
560	80	0.024	0.90	9.7	*IR 72 (-IRRI)	18
400	160	0.030	0.84	16.1	*IR72 (china)	25
2400	100	0.025	0.84	50.4	#	4
2500	80	0.030	0.84	50.4	#	4
2500	80	0.030	0.84	50.4	#	4
1700	120	0.030	0.84	51.4	#	6

*KROPFF, K.G et al.(1993)
Yield parameters for productivity of 50 t ha-1

growth functions occur depending on the degree of their short fall. The relationship between the three basic determinants and productivity is shown in Table -2.

One could easily observe how the plants manipulate the three factors among themselves to get the same productivity-Grain weight increases when spikelets decrease in number; tillering decreases when area per plant is reduced as in high density plantings; spike sterility increases with increase in spikelets number. However the interactions of these factors could vanish favorably under unconstrained supply of resources to get a grain productivity around 50 t ha^{-1}as is shown in Table 2. In Sri Lanka the productivity was stagnating in a large Rice tract and the practices were stream lined over years of experience. On critical examination it showed the productivity was much lower for the nutrients applied. It was found that the productivity was limited by panicles per unit area and advised to increase the hills planted per unit area by ten percent which was followed with about eight percent increase in productivity close to the nutrients they were applying could support.

Water

Water requirement of Rice crop is a made of two parts i.e., (1) Water for maintaining the level of water in the field against seepage and percolation losses which depend on soil characteristics and which is almost a constant irrespective of productivity of the cultivars and (2) the evapotranspiration required for biosynthesis which is related to productivity of the crop. At 40 % harvest index, 2.5 kg biomass is required to be synthesized for every one kg of grain produced. At a mean of 250 kg water per kg of biomass (Ranganathan), one ton of grain per ha requires water equivalent to 62.5 mm rainfall. Seepage and percolation (S&P) losses depend on macro pores and cracks in soil and depends on the soil texture and structure. Puddling with added green manures before transplanting or sowing help in reducing S&P losses. Since Rice is grown in areas of assured water supply, water use efficiency is 70% except in cases of failure of rainfall or skipping of irrigations for reasons beyond one's control. Under these conditions it may go down to 50 to 60%. Taking the mean theoretical limit due to NPP as 48 t / ha (Table1), water dynamics in Rice culture can assure only 70% of that limit (70% of 48 i.e., 34 t ha^{-1}) Water requirement of Rice is given in Table 3. In majority of rice growing areas the rainfall during the cropping season is short of crop requirement and irrigation is a must to make up the

Table 3: Water requirement in mm for the duration of the crop

		At targeted Grain yield of				
crop duration	Soil type	1 t /ha	3 t /ha	5 t /ha	10 t /ha	15 t /ha
70	A	203	328	453	765	1078
	B	413	538	663	975	1288
	C	623	748	873	1185	1498
115	A	293	418	542	855	1168
	B	634	762	888	1200	1513
	C	982	1108	1233	1545	1858
160	A	383	508	633	945	1258
	b	863	988	1113	1425	1734
	C	1343	1468	1593	1905	2218

- *Seepage and percolation losses at : A clayey soils 2 mm d-1 : B medium soils 5 mm d-1 : C sandy soils at 8 mm d-1*
- *biosynthesis requirement per ton of grain- 62.5 mm t-1*
- *Water requirements in rainfall units*
- *Irrigation requirement – water requirement-Rainfall during the crop duration*

shortage to approach the theoretical limits of productivity.

Nutrients

The mean chemical composition of rice plant and nutrients mobilized by the plant for producing one ton of grain (2.5 t biomass) are shown in Table 4. Nitgen is the second largest constituent in the biomass next to carbon which for all practical purposes is not considered a limiting nutrient under normal situations. Hence 'N' is used as an index element toassess the nutrient requirements. As all nutrients are required in proportion to biomass production, nitrogen requirement is estimated for a given productivity level and all other nutrients follow it in proportion to the ratio they maintain in whole plant analysis. In high productivity programs none of the nutrients are allowed to limit the biosynthetic process within the plant. As such all nutrients calculated based on whole plant analysis are given. As the productivity increases, at a particular stage the rates ofdiffusion of nutrients in the rhizosphere becomes a limiting factor as it could not match with uptake rates required by the plant. Such a limiting situation occurred in Tea at the productivity level of 3000 kg ha^{-1}made tea. Further breakthrough in productivity was achieved only after increasing the rates of application of nutrients to increase the diffusion rates by increasing the concentration in soil solution. As the rice is grown in standing water, the large heat capacity of water help to keep the rhizosphere warmer for a longer time against diurnal variations in temperature and help in sustaining high diffusion rates.

At low and moderate productivity levels, contribution of soil nutrients to yield is considerable at 40 to 80 % and cannot be ignored. Soil tests are used to decide on economic doses of nutrients to be applied. At high productivity levels, the contribution of soil nutrients to productivity is less than 15% and hence these are not taken into account. However as these nutrients are in excess to the needs, they help to maintain a higher concentration in soil solution to support high diffusion rate required by the plants to scale up and sustain the rates of biomass synthesis.

Only straw and grain are removed from the field and roots remain in the soil and their nutrient

Table 4: Plant analysis (macro nutrients)

Nutrient elemental form	Chemical composition				Nutrients Mobilized/removed -kg t^{-1}grain			Nutrient Ratio for Application
	Straw	Grain	Roots	Whole plant	A	B	C	
Biomass ratio	40	40	20	100				
N %	0.9	1.5	1.0	1.14	28.50	27.00	23.4	20
P %	0.1	0.3	0.3	0.19	4.75	5.59	3.43	3
K %	2.7	0.3	2.4	1.68	42.00	47.31	30.00	30
Mg %	1.7	1.0	1.4	1.36	34.00	5.43	26.00	24
Ca %	0.3	0.1	0.1	0.17	4.25	6.43	4.20	3
S %	0.4	0.6	0.3	0.46	12.00	2.00	10.00	8
Si %	4.2	1.0	1.3	2.34	58.5	3.74	52.00	?
Cl %	0.6	0.4	0.7	0.53	1.33	0.72	10.00	9

A: Nutrients mobilized per ton of grain (2.5 tons Of biomass) from whole plant analysis
B: Actuals from the experiment
C: Nutrients removed away from the field (Nutrients in straw and grain)

Table 5: Plant analysis (micro nutrients)

Nutrient form elemental	chemical composition				Nutrients mobilized/removed g1000kg^{-1}gain			NR
	Straw	Grain	Roots	Whole plant	A	B	C	
Biomass ratio	40	40	20	100				
Fe g1000kg^{-1}	150	300	90	198	462	-	426	100
Mn g1000kg^{-1}	310	60	90	166	356	-	319	84
Zn g1000kg^{-1}	20	20	10	18	41	-	37	9
Cu g1000kg^{-1}	2	25	7	12	30	-	27	6
B g1000kg^{-1}	16	16	8	14	33	-	29	7
Mo g1000kg^{-1}	1.6	0.7	0.9	1.0	2.8	-	2.3	*0.5

A: nutrients mobilized per ton of grain (2.5 tons Of biomass) from whole plant analysis
B: actuals from the experiment
C: nutrients removed away from the field (Nutrients in straw and grain)NR- nutrient ratios for application
* - required for productivity above 15 t ha^{-1}.

contents are carried forward to next crop. Hence 'N' requirement is calculated based on 'N' removed from the field for every one ton of grain and associated straw harvested and other nutrients in the ratios to'N'as found in whole plant analysis (Table 4 & 5).

Nitrogen replacement thus works out 23.4 kg per ton of grain harvested. Puddling ensures buffering of pH and Redox potential and stabilizes ammonium ions and the efficiency of 'N' is highest in Paddy culture i.e., maximum of 70 % against 30 to 40 % in aerated soils. Taking the average efficiency of soil inherent or applied 'N' as 60%, the application rate needed is 39.0 kg per ton of grain targeted. Other nutrients are applied in their ratios to 'N' found in whole plant analysis. A trial was conducted in Sri Lanka in association with M/s CIC (fertilizers) Colombo to get a targeted yield of 25 t ha^{-1}using the norms discussed above wherein the productivity achieved was 23 t ha^{-1}grains. The short fall was traced to increase in spikelet sterility and omission of Molybdenum.

Rice is cultivated in widely varying soil and agro-climatic conditions.Decomposition of soil organic matter (SOM) and weathering of soils are the primary source of nutrients. The equilibrium SOM content depends on annual additions of organic matter and its rate of decomposition. The rate of decomposition is temperature dependent with organic matter content halving for every 8^0C. Regular addition at12 to 15 tons of organic matter per crop,maintains SOM content nearer to 1% at plains and around 2% at altitude of 1500 to 2000m. As the equilibrium SOM content increases, its decomposition rate decreases with altitude. As such mineralized nitrogen available to plants varies between 100 to 250 kg N ha^{-1} depending on the annual additions irrespective of altitude. Soil structure is important for (1) water storage and to reduce S&P losses (2) for retention and movement of nutrients and (3) sustaining bioactivity. The importance of soil structure for efficient use of nutrients needs no emphasis and is well documented. Threshold productivity of the soil therefore rests on the amount of organic matter and green manures added regularly at the time of land preparation and puddling (Table 6)

Table 6: Soil threshold productivity (without fertilizer application)

Cultivation system	A	B	C	D
Puddling without OM and green manure	100	70	39	1.79
Puddling with OM	150	105	39	2.69
Puddling with OM and green manure	200	140	39	3.59

OM at 10 to 12.5 tons/ha and green manures at 10 to 12.5 tons /ha
A : Soil available Nitrogen kg ha^{-1}
B : Nitrogen used at 70 % efficiency- N kg ha^{-1}
C : N requirement kg t^{-1}grain
D : Threshold productivity - grain t ha^{-1}

For low and moderate targets up to 10 t ha^{-1}, nutrients are applied for the targeted productivity above the threshold potential of the soil ; For high targets above 15 t ha^{-1} the threshold potential of the soil is ignored and nutrients applied for the entire targeted productivity at rates already suggested. However attention to maintain soil characteristics should not be ignored as they are much more important for the efficient use of nutrients in high target programs. 'Mo' needs to be included in high targets above 15 t ha^{-1} as soil 'Mo' level may not able to support the diffusion rates in the root zone to meet plant's requirement. Such a situation occurred in Teawhere the stagnation in productivity at above 4000 kg made tea ha could be broken only with 'Mo' additions.

At the end one should keep in mind that soil turns sick when it is cultivated continually without replacing what has been removed from it in the form of commercial end products. After the harvest when soils start drying, Zeta potential of the electric double layer of exchange sites increases with increasing concentration of soil solution at its surface and collapse at above a critical concentration. At this point soil aggregates crumble to dust which can be blown by the wind. That is why any tilling operation should be done only just before rains or into the favorable conditions. On rewetting, dust particles get restored to original aggregate structure provided minimum salt concentration exists in soil. Regular application of nutrient salts over and above crop requirements are to be made to sustain the physicochemical properties of soil to safe guard the soil tilth on the long run.

The flooded condition is sustained by intermittent irrigation or by continuous flow systems. At the time of applying nutrients, irrespective of irrigation systems practiced, soils are to be drained and fertilizers spread by broadcasting and, then irrigations restored after a brief period not exceeding overnight. Nutrient ions are held by electrochemical potential at exchange sites on soil surface. This thin film of water at the soil surface never moves even when water flows over it as the velocity of water decrease layer by layer due to viscosity effect and approaches zero at the surface. There is no loss of nutrients unless soil moves away and as such suitable soil conservation measures are to be adopted particularly at sloping lands at altitudes above 500m. PH and redox potential determine the phosphate system whose solubility constant maintain available "P" concentration. In reduced soil condition any form of phosphate including rock phosphate can be used. Puddling with green manures and flooded condition help in buffering soil PH and Redox potential. Micro nutrients are held by chelation by organic acids and their availability controlled by hydrolysis constants. Hence phosphates and micronutrients may be applied at the time of puddling. NK fertilizers can be applied in two or three splits taking necessary preconditions cited elsewhere.

Summary

The factors that determine the productivity in Rice culture are brought out and the Research efforts that are currently pursued are also high- lighted. To conclude to sustain productivity; the soil should be left undisturbed after harvest until next planting. A regular application of organic manures such as compost at a rate 10 to 15 tons per ha and green manures at the rate of 10 to 15 t/ha at the time of preparation of the land and puddling help in maintaining soil tilth and in better utilization of resources. P, Mg,Ca, S, and all micro nutrients are to be applied at the time of puddling. NK fertilizers are to be given in the ratio 1:1 for moderate targets and 2:3 for high targets exceeding 15 t ha^{-1} in three splits the first at the time of puddling, the second after transplanting and the third at the time of booting.

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