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Review Article

Approaching Theoretical Limits of Productivity in coconut

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Abstract

Approaching theoretical limits of productivity of a crop in a given situation requires knowledge about theoretical maximum productivity possible for the phyto-climatic potential of the region, a function of ideal climatic conditions with unlimited supply of nutrients. However ideal conditions never exist; climatic variations and soil heterogeneity imposes a correction factor and the productivity varies widely from zone to zone. Agro climatic potential takes into account variations in temperature, rain and irrigation water use efficiency and, sunshine hours through the growing season to arrive at productivity that could be achieved when other management factors are not limiting it. (*Ranganathan, 2014*). In any situation, there are two facets of limiting forces to look into before deciding the target. (1) The maximum productivity achievable with the climate – temperature, sunshine hours and rainfall and its distribution is called climate limiting threshold productivity under rain fed conditions. Of these, only water availability is manageable and it is known as the threshold limit with irrigation potential of the area. (2) The threshold productivity from nutrients available through natural recycling process with or without recycling the organic residues at harvest. Only the economic end product for which the crop is grown, should be taken away from the field. The threshold productivity depends on soil's physical, chemical and physicochemical properties of soil, particularly soil structure stabilized by humus compounds which play important role in water storage, retention and release of nutrients for the growth of plants. This part is looked after by recycling of all crop residues other than the economic end product, addition of organic matter and raising green crops and plough them in situ before planting or as inter crops in tree gardens. These are referred as soil factors limiting thresh hold potential. (3) The target is fixed between the above two limits depending on nutrients availability and other factors like labor availability, logistic factors for handling higher volume of the product and demands in the market. Discussions are restricted only to the role of water and nutrients to achieve a set target in productivity in this paper.

Keywords

Threshold, Maximum and limits of productivity .

Introduction

Coconut is a tropical high value plant growing mostly between 20^0N and 20^0S in various types of soil such as loamy, laterite, coastal sandy, alluvial clayey and reclaimed marshy low lands. The important climate and crop details are given in Table 1.

The theoretical maximum expectation of productivity is viewed from three different angles as follows:

1 *Plant biology:* Theoretical maximum yield from plant point of view is 3600 nuts per tree per year, assuming 300 female flowers succeed in fruit setting and 12 bunches, are formed and harvested in a year. Then the theoretical figure is achieved. But

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Table 1: Climate and Plant Factors

Rainfall	150 to 250 cm
Temperature	24 to 29^{0}C
Altitude	< 600 m
Latitude	20^{0}N and 20^{0}S
Solar energy incident	6000 to 6700 MJ m^{2} yr^{-1}
Photosynthetic efficiency	0.29 (0.64 on PAR)
Respiration losses	Around 15%
Critical minimum "t^{0}C" for growth	10^{0}C
Differentiation of flower primodia to flowering	22months
Nut maturity period	11.5 t0 12 months
Average leaf production	0neper month
Average number of leaves at any one time	26
Plants per ha	100 to 250
Nut yield per tree per year	80 to 250
Copra yield t/ha	2 to 4

Inflorescence: Monoceious, staminate and pistilllate flowers maturing at different times. Cross-pollinated by wind and insects; Maximum pistillate flowers- 300 ;

A monocot - Continuously forming adventitious roots from the base of the trunk; No tap roots or root hairs but have lot of primary roots with lot of rootlets; root growth is more horizontally (up to 10 m) than geotropically (3 to 4 m); low root CEC to compete for monovalent ions in base deficient soil solution.

only about 10 to 25 % female flowers are successfully pollinated under natural conditions limiting the natural expectation to around 720 nuts per tree per year (Table-2).

2. *Maximum NPP:* Theoretical maximum productivity is estimated as net primary production under conditions of unconstrained availability of resources from the solar energy incident on earth surface, photosynthetic efficiency (PE), respiration losses, energy required to biomass synthesis(19MJkg-^{1}biomass) and the efficiency of natural recycling process (60to 70%) limited by thermodynamic laws. The net primary production is about 14to 16 % of biomass equivalent of energy incident on the surface. The maximum productivity under unconstrained availability of resources (CO_2 Water, and nutrients) so arrived is around 480 t biomass ha^{-1} yr^{-1}. Recent studies report that the maximum NPP approached 200 t C ha^{-1} yr^{-1} (about 450 t biomass ha^{-1} yr^{-1}) at point locations roughly two orders of magnitude higher than current managed or natural eco systems.(*de Lucia et al.*). For discussions here afterwards the maximum NPP used is 450 t bio-mass ha^{-1} yr^{-1}. The maximum productivity that can be approached under

Table 2: Maximum nuts per tree under unconstrained availability of resources from NPP data

Theoretical productivity					Bio-mass distribution in coconut (%)				
A	HI	NW	PD	NP	NUT		Other Parts		
					Nut shell & husk	Copra	Fronds	Others	Roots
450000	0.45	1.8	100	1125					
450000	0.45	1.8	150	750	36±4	9±3	32±2	9±4	14±2
450000	0.45	1.8	200	563	45±3			55±3	

A-NPP (Biomass kg^{-1} ha^{-1} yr^{-1}) : HI - harvest index : NW –Mean nut weight in kg ; PD – Average Planting density palms per ha; NP- Nut productivity (nuts per tree per year)
studies report that the maximum NPP approached

unlimited supply of resources vary between 563 and 1125 with a mean around 750 nuts per tree per year at normal planting at 150 palms per ha, very close to pollination limited maximum productivity of 720 nuts per tree per year

3. *Constraints-Water availability:* The main constraint to approach near the theoretical maximum limit of productivity is availability of water. As biomass production from the carbohydrates use respiration energy, it is related to water transpired and evaporated which help to maintain cell temperature at optimum for the reactions to proceed at optimum rates. The physiologists have shown that about 250 kg of water has to be transpired for every kg of bio-mass and the seasonal variations in growth is due to water availability when temperature is not a limiting factor. After the rain stopped or after the irrigation .the plant growth is sustained by the water stored in the soil, The water storage capacity depends on soil structure defined in terms of porosity (micro meso and macro pores) and bulk density and which in turn is sustained by organic matter status of the soil. In tropical coconut soils, OM can be maintained at or around 0.4 % and water holding capacity is around 44% About 50 % water stored is available to plant (Ranganathan) which gives an average water storage capacity equivalent to about 36 cm rainfall to a depth of 150 cm. The rainfall/irrigation water use efficiency is arrived as follows (Ranganathan):

$$R = 1 - e^{-(Fm + Rm - ET)/F}$$

(Where R- Rain/irrigation water use efficiency ; "Fm"- water storage at the beginning the month in ha cm ; "Rm" – rainfall or irrigation during the month in ha cm : "ET" – evapotranspiration during the period in ha cm ; "Fm" is always limited to "F" water storage capacity of the field if "Fm" at the beginning of the month is higher than "F " :'R' is the probability of leaf water remaining above critical level for growth).

"R" reflects the water availability in the soil for a given period and for tree crops such as coconut, "R" values are calculated monthly and the average of monthly values are taken as the "R" values for the year. During Drought "R" values are low and in irrigated areas irrigation compensates and improves the "R".

Thus, there exist two threshold limits relating to water availability as a constraint i.e., One without irrigation and another with irrigation.

"R" values expressed as % is a rough estimate of water that could be used by the plants out of total water input (rainfall + irrigation) with practical significance. It is about 45 % for Odissa with irregular long drought periods; 50 to 55% for most of coconut growing areas with about 3 months drought . In irrigated gardens "R" values reaches to around 60 to 65 %.

To produce one nut with a mean weight of 1.8 Kg, palm has to manufacture 4.0 Kg total bio-mass at 45 % Harvest index. At 250 kg of water per kg of bio-mass, one nut requires 1000 kg (Litres).

On this basis of above requirements, rainfall limits the approach nearer to theoretical maximum productivity with and without supporting irrigation as shown in Table 3:

To approach the theoretical limit of productivity with un-constrained availability of nutrients, a well distributed annual rainfall of 1730 cm is required (Table -3).

Table 3: Water limiting the productivity under unconstrained availability of nutrients

Climate zone	Rainfall cm	R %	AW ha cm	WR/nut L yr^{-1}	Nuts 10^3 ha^{-1}	Nuts per tree per year at Palms density of		
						100 /ha	150 /ha	200 /ha
	112	45	50	1000	5.0	50	34	25
With Irregular drought as in ODISSA	150	45	68	1000	6.8	68	45	34
	200	45	90	1000	9.0	90	60	45
With regular short droughts as in most of the areas and monsoon rain areas	112	55	62	1000	6.2	62	41	31
	150	55	83	1000	8.3	83	55	41
	200	55	110	1000	11.0	110	73	55
With supportive irrigation to compensate in dry periods and areas with well distributed rain fall	112	65	73	1000	7.3	73	49	36
	150	65	98	1000	9.8	98	65	49
	200	65	130	1000	13.0	130	87	65
	300	65	195	1000	19.5	195	130	98
To approach theoretical limit of productivity	1730	65	1125	1000	112.3	1125	750	563

R –Rainfall/irrigation water use efficiency; AW- water used by the plant; WR- Water requirement liters per year ,per nut (Mean weight of 1.8 kg); Nuts in thousands per ha

4. Constraint Nutrients: Seven elements (C, H, O, N, P, S, Ca) make up the biomass while K helps in water relations, Cl in maintaining ionic balance and other micronutrients help in bio-cycles to form various chemicals for the holistic growth of plants and expression of their genetic characters. As such all nutrient elements are required in proportion to the bio-mass they produce The chemical composition and nutrient requirements are given in Table-4.

The natural recycling process such as weathering of soil, Nitrogen cycle, alluvial and erosion deposits, and returning plant residues to the soil maintain certain equilibrium level of availability of nutrients which sustains a threshold level of productivity.

Table 4: Chemical composition and nutrient requirements

Particulars	BM	Chemical composition % N	P	K	Mg	Ca	S	Na	Cl
1 Whole palm	55	0.25	O,04	0.40	0.03	0.05	0.03	0.06	0.32
2 Nuts (with husk)	45	0.23	0.03	0.26	0.14	0.10	0.13	0.30	0.38
Nutrient requirement for biomass production in kg per nut									
Nutrients for one nut 1.8 kg at 45% HI i.e. , 4kg biomass		0.0100	0.0016	0.016	0.0012	0.0020	0.0012	0.0024	0.0128

BM biomass distribution in coconut HI harvest index

Major contribution of Soil availability of nutrients comes from the decomposition of the organic matter.

The decomposition is of first order kinetics and the equilibrium 'OM' status is equal to "$(A = A_n)/k$" where 'A' is equilibrium 'OM' status , 'A_n' is the annual additions and 'k' is the decomposition coefficient . 'k' is 0.95 for tropical cultivated soils. To maintain an organic matter status at around 1% to a depth of 25 cm ,an annual addition of 26 t OM /ha is required: It works out to 2.6 times the area in m^2 per tree in kg per year . Recycling materials available is about 110 kg per tree per year mainly consisting of leaf fronts, spike, spathe, immature nut falls husk shell and others. Husk and shell are taken away leaving the recycling residues available to about 70 kg per tree or around 11 t ha^{-1}. Coir dust is used to improve soil aeration in clayey soil. The above returns to soil will sustain an 'OM' status around 0.3%.

The rest of the 'OM' has to come from extraneous sources or raising green manure crops and plough in at its maturity.

A well managed coconut garden or orchards has a 'OM' content around 0.3 to 0.5 % against less than 0.2% in cultivated soils of annual crops. The decomposition of every one % of OM in tropics releases about 150 kg of N /ha and proportional amounts of other nutrients as seen in the bio-mass the efficiency of soil 'N' is only around 30 % mainly due to inevitable leaching and de-nitrification losses. As 'N' decides the bio-mass production next to 'C', the uptake of other nutrients follow that of 'N' in ratios found in whole plant analysis to sustain the holistic growth leading to higher productivity. Hence 'N' is an indicator for crop requirements and other nutrients are to be considered in proportion to 'N' needs in the ratios needed for the crop based on the whole plant analysis. The importance of 'OM' in soil based agriculture is much more than this i.e. it sustains the soil structure (synonym for soil fertility) for water storage, and circulation of water, air and nutrients in the rhizosphere. The chemical composition of the Palm and nutrient requirements to produce one nut of 1.8 kg average weight which requires 4 kg bio-mass production are shown in Table-4.

Table 5: Soil threshold limits of productivity

Management System	Soil OM%	Mineralized N kg ha^{-1}	Soil Available NKgha^{1}	N per nut Kg	Nuts ha^{-1}	Number of Nuts per tree at planting density of		
						100/ha	150/ha	200/ha
A	0.3	50	15	0.01	1500	15	10	6
B	0.5	75	25	0.01	2500	25	17	13
C	0.8	120	40	0.01	4000	40	27	20

A- Partial recycling of crop residues : B- 100% recycling of crop residues: C-Recycling + extraneous sources of OM @ above 10 t ha^{-1} yr^{-1} or raising and plough in of green manure crops

The threshold productivity of soil depends on the nutrients available through recycling process and are estimated through 'OM' status and its decomposition rates dependent on mean annual temperature of the area. Since other nutrients keep a ratio to nitrogen content for obvious reasons, threshold productivity is calculated using 'N' requirement to synthesize bio-mass from NPP. Threshold productivities under different 'OM' management systems are computed and shown in Table -5.

The threshold limitsof productivity imposed by climate, rainfall and biological are summarized in Table 6.

Nutrient efficiency increases with the productivity of the palms. This is because the retention time of the nutrient in soil to undergo transformation such as fixation and losses are reduced with higher rates of uptake as the demand per unit time increases with productivity

Threshold limits of productivity imposed by climate, rainfall, biological and nutrient factors are summarized below in Table 6.

Table 6: Threshold limits of productivity imposed by climate, rainfall, biological and nutrient factors

No	Factors	Constraints	NPP used as biomass t $ha^{-1}yr^{-1}$	Palms /ha	THERSHOLD Limit nuts /tree
1	Biological	Unconstrained resources	-	-	3600
2	Biological	Fertilization limiting ;other resources not limiting	450	156	720
3	Climate	Water and nutrients not limiting	450	200to100	563 to1125
4	Rainfall up to 200cm	Nutrients not limiting	20to44	200to100	25 to 110
5	Rainfall up to 200 cm +Irrigation	Nutrients not limiting	29to52	200to100	36 to130
6	Rainfall 300 cm+ irrigation	Nutrients not limiting	78	200 to100	98 to 195
7	Nutrients (Soil)	Climate and water not limiting	6 to 30	200to100	6 to 50

Table 7: Nutrient Requirements for Targeted yields- Nitrogen

Soil status	Palms /ha	Targets Nuts/ha	Target Nuts /ha	Threshold Productivity Nuts /ha	Nuts to be manured Nuts/ha	'N ' requirement for additional productivity targeted 'N' Kg/nut	'N' Kg/ha	'N' Kg/tree	'N' to be added kg/tree
A	100	65	6500	3000	3500	0.01	35	0.35	0.70
	150	87	13050	4500	9000	0.01	90	0.90	1.80
	200	130	26000	6000	20000	0.01	200	1.00	2.00
B	100	65	6500	4500	2000	0.01	20	0.20	0.40
	150	87	13050	6750	6300	0.01	63	0.63	1.26
	200	130	26000	9000	17000	0.01	170	0.85	1.70

A-with partial recycling of plant residue with threshold productivity of 30nuts/tree/yearB-With 100% recycling of plant residues with threshold productivity of 45 nuts /haRainfall 200 cm uniformly distributed or with supported irrigation during dry months

Target is fixed taking into account the rainfall, its distribution and irrigation potential available above the threshold productivity of nutrients available in the soil. Nutrients are added for the productivity targeted above what the soil could support.'N' so calculated is added taking into account of the efficiency of applied and inherent nutrients in the soil.

'N' efficiency is around 30% in low yielding palms; but it is around 50% when the productive levels are high. Similarly the efficiencies of all nutrients increases with productivity. The calculation of Nitrogen requirements for targeted yield is shown in Table 7.

Other nutrients are applied in ratios seen in whole plant analysis Table 8.

As soil structure is built over thousands of years by leaching of humic acids down the profile, it is important to preserve the profile at any cost.

Table 8: Ratios of nutrients to be applied in normal soils for Coconut

N	P	K	Ca	Mg	S	Na	Cl
15	2.5	22.5	3.0	1.8	1.8	3	18

Returning the crop residues, mulching green manure additions and preventing soil erosion by all available means regularly helps in maintain soil structure down the profile and help in economizing on fertilizer bill. No tillage or minimum tillage practices help to achieve the above. This could be realized in a regular system of management as follows:

1. Rock phosphate, calcium carbonate or calcium sulfate (gypsum) depending on soil pH, magnesium sulfate, and micro nutrients can be applied in a circular trench 1 m away from the base of the palm once in 3 to 4 years and the trenches closed and covered with mulch materials and crop residues. Every year crop residues are chopped and spread around the palm along with other organic materials available. Before that, about 1.5 kg NaCl may be broadcasted uniformly within 1.5 to 2 m radius around the tree. This system will reduce the soil disturbance to the minimum and saves lot of labor and time for other operations.
2. NK can be applied broadcast in 2 to 3 applications when the soils are moist or in between two spells of rainfall, or just before irrigation. When NK are applied on moist soil, they are retained in by electrochemical forces reducing the losses thereafter even when the conditions turn unfavorable till rains come or irrigation carried out.

Summary

Various factors, climate, water, plant soil and nutrients, that are to be considered in attempting to exploit the theoretical limits of productivity are discussed. Targeting productivity appropriate to availability of resources and, calculating nutrient requirements and their methods of application with little soil disturbance as warranted by modern "Zero tillage or minimum tillage" concepts are discussed.

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