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Net Primary Production (NPP) in Tea (*Camellia L. spp.*): A Overview

V. Ranganathan

Author's Affiliation: Consultant, IMT Technologies Ltd., Pune, Maharashtra 411004, India.

Abstract

Several attempts were reported about the theoretical maximum yield potential (NPP Net Primary Production) of tea plant from time to time. Some of them are discussed to bring out the large gap between NPP and what is achieved and to highlight the important facets that are to be looked into for sustaining economic productivity

Keywords

Net Primary Production; Constraints to Productivity; Critical Analysis.

Introduction

With the advent of information on the interactions of soil, water, nutrients, plant and climate (as defined by rainfall temperature sunshine hours) by thirties and forties of last century, there is always an on-going urge to identify NPP (Net Primary Production). Attempts are made to chase the productivity to get it nearer to what could be achieved under a given set of soil and agro-climatic conditions. Various crop husbandry, nutritional, and harvesting techniques were fortified to increase and sustain productivity at a targeted level (Ranganathan 2014, 2015, 2016, 2017 2018). Herein an attempt is made to recapture the past documentations on this discipline and to bring out the important constraints that are to be looked into towards achieving the goal.

Net Primary production

The primary source of energy for plant growth is solar radiations incident on earth surface. Under unlimited availability of resources (water and nutrients), the NPP is arrived using its energy content, and its conversion ratio to biomass. NPP arrived by various workers from time to time is summarized in *Table 1: EiCi* (Energy captured and fixed in biomass) at 14% gives comparable values of NPP as arrived thru recent satellite studies. The early workers used the maximum energy that could be captured and used by monocots and dicots at 4 % and 6 % respectively. NPP at 450 t biomass per ha per year as indicated by satellite studies of De Lucia et al. (2014) is used for discussions in this paper. Basic data on nutrient composition of tea plant as compared to plants in general and their sources of availability in nature which are used for critical reviewing in this manuscript are summarized in Tables 2, 3, 4 and 5.

Water Requirement Quantification

Water is required to keep living biomass in dispersed phase and the amount so bound in tissues commonly referred as "Tissue moisture". It is small compared to water required to keep the tissue temperature at optimum levels against the temperature increase during synthesis of biomass using respiration energy. For synthesis of every one kg of biomass, around 250 kg of water is transpired and the growth, therefore, is the function of amount of water transpired. Water, thus, becomes the prime limiting factor in crop productivity in a climatic zone. As soil aeration is required for bioactivity, nutrient movements and to aid transpiration, a slight negative water potential has to be maintained by intermittent desiccation of soils. As such water use efficiency is always less than one. Water use efficiency (R), the probability that leaf water potential is maintained at or above critical level, represents rainfall or irrigation water use efficiency. Basis of the concept and its computation are discussed by Ranganathan (2014).

"R" values of some tea growing areas are given in Table 6.

Corresponding Author: V.Ranganathan,
Retired Scientist,
Block-12, Flat H-1 Jains Green Acres 91 Darga Road,
Pallavaram, Chennai 600043 Tamil Nadu.
E-mail: vedantarangan@yahoo.com

Table 1: NPP (NET Primary Production) Under unlimited supply of resources

	SR $TJha^{-1}yr^{-1}$	E to B $MJ\ kg^{-1}$	PP $t\ ha^{-1}yr^{-1}$	@EiCi	@NPP $t\ ha^{-1}yr^{-1}$	#EiCi	#NPP $t\ ha^{-1}yr^{-1}$
*1	61.12	18.83	3245	0.14	454	0.06	195
*2	78.84	18.83	4186	0.14	586	0.06	251
*3		De lucia et al (2014)			450	xx	450

SR Annual integral of incident radiation TJ per ha/year

*1 - @ 400 calories cm2 day-1 used by early workers equivalent to 16.7 MJ m-2 day-1

*2- @ 21.6 MJ m-2 day-1 from recent data

E to B ;Energy to biomass MJ kg-1

*1- at 4500 calories per g biomass ; values of E to B 17.5 to 19.0 MJ per Kg are also reported

@EiCi; Energy captured and used is about 14 to 16 % of biomass equivalent energy incident on the surface; #EiCi -early workers used 4 and 6 % for monocots and dicots respectively

*3: using the maximum NPP 200 t Carbon ha-1 yr-1or 450 t biomass ha-1 yr-1 (de lucia et al 2014)

Table 2: NPP and Dry matter distribution and chemical composition of tea plant

Net Primary Production			Chemical composition								
						A				B	
	t/ha	%	C	O	H	N	P	S	Ca	K	Mg
Parts of tea plant						Composition %					
Flush (manufactured)	90	20	44	44	6	2.5	0.50	0.20	0.40	2.00	0.25
Maintenance Foliage	99	22	45	45	6	2.2	0.35	0.13	0.48	0.80	0.80
Wood + Twigs	180	40	46	45	6	1.2	0.26	0.12	0.60	0.40	0.15
Roots	81	18	45	45	6	1.2	0.24	0.20	0.45	1.80	0.24
Whole TEA Plant	450	100	45	45	6	1.7	0.32	0.15	0.47	1.06	0.20
Plants general			45	45	6	1.5	0.20	0.10	0.50	1.00	0.20

A-Elements that make up the bio mass; B-mineral elements in ionic from for osmotic regulations and specific roles in bio synthesis acting as co-enzymes

Table 3: Composition of plant biom ass-mineral nutrients

B-- mineral elements in ionic form for osnotic regulations and specific roles in bio synthesis acting as co-enzymes										
Parts of tea plant	Cu	B	Mo	Zn	Mn	Fe	Al	cl	Na	Si
					ppm					%
Flush (manufactured)	40	30	<1.0	40	850	200	1000	60	80	0.8
Maintenance Foliage	120	90	<1.0	120	1000	400	1200	150	90	0.8
Wood + Twigs	40	40	<1.0	40	450	150	1000	60	140	0.9
Roots	40	40	1.0	40	120	150	1200	60	130	0.9
Whole TEA Plant	49	40	1.0	58	591	215	1080	80	115	0.9
Plants general	6	20	1.0	20	50	100	N/A	100	100	1.0

Al: - passive uptake accumulates in mature foliage reported contents vary widely

Si-in soil based systems, its uptake is inevitable. In some instances up to 10% or more reported

Silicon:- most of it is precipitated in cell walls giving strength mainly to C_3 monocots and dicots plants : in tea it also helps in assimilation and release of carbon dioxide for photo synthesis in association with potassium and Boron.

Chlorine:- uptake varies widely depending on the need to maintain electrical neutrality in cell plasma

Na:- a complimentary monovalent ion, higher than 100 ppm ix toxic; uptake controlled by applying larger quantities of Potassium

Table 4: Resources for plant groth

Earth crust		Atmosphere		Hydrosphere		Soil available Nutrients	
Element	**mass**	**Gas**	**content**	**Element**	**mass**	**Element**	**Content**
Oxygen	49.13	Nitrogen	78.10%	Oxygen	89.89	C	0.45 to 4.5%
Silicon	26.00	Oxygen	20.95%	Hydrogne	10.89	O	0.45 to 4.5%
Aluminium	7.45	CO2	300 ppm	Chlorine	1.90	H	0.06 to 6.0%
Iron (Fe)	4.20	N2O	0.5 ppm	Sodium	1.06	N	200 to 600 ppm
Calcium	3.25	Hydrogen	0.5 ppm	Others	0.33	P	1 to 10 ppm
Sodium	2.40	OZONE	0.4 ppm			K, Mg, Ca	100 to1200 ppm
Potassium	2.35	Methane	1.5 ppm			Mo, B	1 to 2 ppm
Magnesium	2.35	Inert gases	9308 ppm			Zn, Mn, Fe	128 to 535 ppm
Hydrogen	1.00					Cu	11 ppm
Others	1.87					Si	100 to 3000 ppm

Soil available nutrients-S, B, Cl, S by water extraction, Cu by ammonium acetate extraction and others by EDTA extraction

Table 5: Soil available Nitrogen-mineralization of OM

Altitude	MQ	OM added	OM added	OMss	N released per 1% OM	N Released
m MSL	k	t/ha/yr	as OM% A	% A/k	kg/ha	kg/ha/yr
less than 250	>0.80	40.0	1.33	<2.0	>200	180-200
250-1500	0.25±0.10	34.6	1.15	1 to 2	80 to 120	100-200
500-1500	0.20±0.06	22.9	0.76	2 to 4	40 to 60	100-200
100-2000	0.10±0.03	16.8	0.56	4 to 8	20 to 30	100-200
2000-2500	0.05±0.02	14.0	0.47	8 to 10	15 to 30	100-200

Altitude m MSL; MQ- OM mineralization coefficient; OMss; Steady state OM

OM added mean per/t/ha/yr.-as 1) shade tree lopping and leaf fall, 2) Tea litters and pruning, and 3) weeds, contributing 48%, 47,%, and 5% respectively

A- Om added converted to equivalent OM % in soils to a depth of 30cm assuming soil bulk density of 1.0 i.e. One he of soil with 1% Om isequivalent 30 t Om to a depth of 30 cm OMss = A/k Rangnathan et al (1980)

Table 6: Water Use efficiecy Coefficient "R"

country	Region	Rainfall cm	"R"
S.India	Anamallias	400	0.73
S.India	N wynaad	201	0.69
S.India	Malabar Wynaad	290	0.75
S.India	Vandipeiyar	211	0.66
S.India	Ooty Nilgiris	163	0.61
NE .India	Assam	206	0.69
Africa	Malawi	177	0.65
SriLanka	Kandy	198	0.67
SriLanka	Ratnapura Low country	409	0.80
SriLanka	Passara UVA	228	0.72
SriLanka	St.Coombs,Talawakelle	219	0.83
Mean	246	0.71	

"R"- 1 – e-(Fm +Rm-ET)/F (after Ranganathan 2014)

Table 7: Water limiting productivity under unconstrained supply of nutrients

Matter	Rainfall cm	RE	Available water Kl/ha	Water to biomass l/kg	Biomass t/ha	Made tea t/ha
High rainfall areas	400	0.71	28.40	250	114	23
Average rainfall areas	240	0.71	17.04	250	68	14
For NPP	1584	0.71	112.50	250	450	90
One irrigation	2.5	0.71	0.20	250	1	0.14

RE- mean water use efficiency: Available water thru rainfall (and irrigation) used by the plants in kilolitres/ha: made tea at 20% harvest index

Mean "R" value (0.71) is used for discussions in this paper. "R" is related to water that could be stored to a depth of soil foraged by 90% roots and hence depends on soil OM and, soil textural and structural characteristics.

Constraints Water availability

Water requirement to reach NPP under unconstrained supply of nutrients is about 1584 cm of well distributed annual rainfall. Annual rainfall of tea areas vary between 180 and 400 cm. Maximum yield they can support is 23 t/ha in high rainfall areas with a mean rainfall of 400 cm and 14 t/ha in other areas having an average rainfall around 240 cm (Table 7). Almost all tea areas face alternate wet and dry periods with inherent strength to get through adverse periods. Tea responds to irrigation during dry periods and one irrigation normally equivalent to 2.5 cm rainfall can boost up the yield by 140 kg/ha.

Constraints Nutrient Availability

The threshold limit of productivity due to nutrients available through natural recycling of them comes next as the limiting factor. Nutrients required to sustain a targeted productivity are calculated for the total biomass to be produced based on harvest index. As N requirement is highest next to Carbon and oxygen, nutrient requirement is always based on its needs with support of all other nutrients added in the ratios that occur in whole plant analysis.

At the harvest index of 20%, one kg of made tea is derived from 5 kg of bio mass which require 0.085 kg N (Table 2). On this basis to produce one kg made tea, it requires 0.085 N with all supportive nutrients at the ratios seen in whole plant analysis. Nutrient elements are derived from weathering of soil minerals and decaying OM and move up and down the root zone by gravitational and evapotranspiration currents.

Under unconstrained availability of water, natural bio and mineral recycles of nutrients maintain a steady state equilibrium of nutrient contents which support and sustain a thresh hold limit of productivity. Table 8 shows the threshold productivity of tea soils which lie in between is 400 and 1200 with an average of 900 kg /ha. The efficiency of utilization of soil N is 30% in low yielding Tea and goes up to 70% in high yielding Tea. An average value of 50% in medium yielding situations and 70% in high yielding situations are used in the discussions Tea soils can give a maximum productivity of 1142 Kg /ha provided all nutrients are available in ratios as seen in whole plant analysis. But, K poses as a limiting nutrient in soils at productivity level above 800 to 900 kg / ha and as such under no fertilizer management the threshold productivity recorded was always lower than 900 kg/ha.

Table 8: Threshold productivity of Tea soils

Soil available "N" kg/ha (Table 5)	Efficiency Coefficient "N" to	"N" made tea (Table 2)	Made tea Kg/ha
100	0.5	0.085	588
200	0.5	0.085	1176
	Mean		882

Targeting Productivity

Productivity of a region could be targeted to lie in between the soil threshold level of 900 kg/ha and the constraint imposed by water availability i.e. 23 t/ha in high rainfall areas with a mean rainfall of 400 cm and 14 t/ha in other areas having an average rainfall around 240 cm. Having fixed the target yield, there are three ways fixing the rates of nutrients application 1) Nutrients' rates are then calculated for the yield to be achieved above the soil threshold limit as explained earlier and applied. 2) Nutrients' rates are arrived for the targeted yield and the difference between them and that are available in the soil are applied. 3) In very intensive systems of management nutrients are applied for the targeted yield ignoring the soil available contents. They serve as the minimum concentration of ions that are required to sustain soil electrochemical potential against plants' uptake and leaching losses to maintain soil structure against cycles of soil desiccation and wetting.

"P" is fixed in soil as sparingly soluble phosphates of Fe, Al, and Ca depending on soil pH and redox potential. P does not move in soil and roots go in search of it. As sub soil is moist for a longer period it is always placed in the sub soil. This helps in deeper rooting and helps in uptake of P as well as other nutrients for a longer time. P accumulates in soil and availability ensured by solubility product constant. As placement is labour intensive, 2 to 3 year needs can be applied at a time. In Tea, the application is done twice- one in the pruned year and the second one in 3, 4 or 5th year depending on the length of pruning cycle.

Ca and Mg requirements are met through regular liming. In magnesium deficient situations, dolomitic limestone, or a mixture of limestone and magnesite is used as liming material. In highly decayed acidic soils with low soluble silica, part of liming material is substituted with magnesium silicate.

The availability of Fe, Mn, and Al in acid soils is not a problem. However, a small quantity Mn is added to micronutrient formulations intended for foliar applications to enhance cell permeability for their absorption.

S needs are met by using ammonium sulphate to supply about 40 to 50% of Nitrogen needs.

Nutrient elements which face deficiency in their supply thru natural recycles requiring additions pro rata to target productivity are N, K, Zn, Cu, B and Mo. Retention and release of N and K ions and their movement in root proximity are controlled by soil exchange and physiochemical properties of soil colloids. Micronutrient ions are retained as chelates of organic acids from decomposing organic matter and their availability controlled by hydrolysis constants of the chelate complexes. As such all these nutrients can be applied broadcast on a moist soil. Subsequent rains do not carry them away from the site as the velocity of runoff water approaches zero at soil surface and thin layer of water on the soil surface does not move .Nutrient losses occur only when the soil moves and the importance of soil conservation measures needs no emphasis The rates of application of these of these nutrients for targeted productivity are given in Table 9.

Table 9: Nutrients' requirement for 1000 kg /ha

index	'N' kg	'K' kg	'Zn' g	'Cu' g	'B' g	'Mo' g
A	84	53	29	25	20	0.5
B	123	66	36	31	25	0.6
C	123	123				

A – based on whole plant analysis;
B- corrected for efficiency of utilization of nutrients from soil solution

C-correction for synchronizing diffusion rates with uptake rates in high yielding situations

The nutrient requirements for certain targeted productivity levels are shown in Table10.

Ending Up

The theoretical maximum achievable productivity is 23 t/ha and 11 t/ha in high rainfall areas and other areas respectively. As a thumb rule it is around 5.5 t/ha for 100 cm rainfall. But the productivity achieved so far is far below what could be achieved in a region.

Tea has adapted specific adaptations to shade influenced by the photosynthetic C3 mechanism and related processes, mainly light capture, electron transport, carboxylation and photo inhibition at high light intensities. The yield is sink- limited as shoots are plucked before maximum bio mass fixation. As such harvesting requires maximum attention in all aspects to get highest biomass fixation in harvest without loss in quality. Even after giving a correction to biomass distribution between tea and shade at ratio of 80:20,the maximum yield achievable in a region is about 4.4 t/ha for every 100 cm water in rainfall units – 18.8 t/ha in high rainfall areas and 8.8 t in other areas.

Table 11 gives the recent productivity trends in India. There is a scope for vertical growth in productivity which could be advantageously exploited for releasing low cropping and disputed stretches adjacent to wild life sanctuaries to afforestation without slipping from the global second position in production, export and consumption.

Table 11: Productivity trend (kg/ha)

year	North India	South India	INDIA
1991-95	1631	2260	1779
1996-00	1711	2015	1776
2001-05	1602	1897	1681
2006-10	1623	1984	1696
2010-15	2029	1982	2019
2016	2292	1771	2275
2017	2275	1934	2204

Source: Tea Board , Upasi Trf

Table 10 : Nutrient requirements for certain yield targets

Target	Target kg/ha A	TP kg/ha B	Difference in yield (A-B)for manuring kg/ha C	Application rates		F*
				N kg/ha D	K Kg/ha E	
<3000kg/ha	1900	900	1900	123	66	6
<3000kg/ha	2900	900	2900	246	132	8
>3000kg/ha	3400	900	3400	418	418	12
>3000kg/ha	3900	900	3900	479	479	12

TP-Threshold productivity; F*- traditional way of expressing 'N' requirement as kg 'N' per 100 kg made tea

Note that for target yield above 3000kg /ha requirements are calculated for the targeted yield ignoring what soil could support

Tea responds to water and nutrients and management practices, an in-built promising feature to sustain economic productivity in intensive management systems.

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