



## Effect of Fertigation Through Drip and Micro Sprinkler on Physiological Parameters in Cocoa (*Theobroma cacao* L.)

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A field experiment to study the influence of fertigation of N, P and K fertilizers on physiological parameters of cocoa (*Theobroma cacao* L.) was conducted at the Department of Spices and Plantation Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore during January 2010 - December 2011. The experiment was laid out with thirteen treatments replicated three times in a randomized block design. The fertigated plants especially with water soluble fertilizers were observed to be in a better physiological state at different stages of crop growth when compared to plants fertilized in the conventional manner. Among the treatments, T<sub>4</sub> (125 per cent 'Recommended Dose of Fertilizers' as water soluble fertilizers (WSF) through drip irrigation) increased the physiological parameters viz., leaf area (325.4 cm<sup>2</sup>), specific leaf weight (6.48 mg cm<sup>-2</sup>), total chlorophyll content (2.01 mg g<sup>-1</sup>), nitrate reductase (1.57 µg of NO<sub>2</sub> g<sup>-1</sup> h<sup>-1</sup>), peroxidase (0.89 D430 nm g<sup>-1</sup> h<sup>-1</sup>), C/N ratio in leaves (14.6 %) and stomatal characters like stomatal length (17.3 microns), stomatal breadth (13.9 microns), stomatal size (225.8 µm<sup>2</sup>).

**Key words:** Fertigation, drip, micro sprinkler, physiological parameters, water soluble fertilizers.

Cocoa (*Theobroma cacao* L.) the 'Food of Gods' is one of the most important plantation crops consumed worldwide and around 40 - 50 million people depend on cocoa for their livelihood (World Cocoa Foundation, 2011).

Cocoa is intercropped with coconut and arecanut and is a good companion to these crops. Kerala, Andhra Pradesh, Tamil Nadu and Karnataka states share the major cocoa production in India. The current area is estimated to be 46,318 ha with production of 12,954 MT and the national productivity is 550 kg dry beans per ha. Tamil Nadu occupies third in cocoa cultivation and the area reported under this crop is 15,000 ha with an annual production of 350 MT (DCCD, 2011).

More than 80 per cent of active roots in cocoa are located within the radius of 30-60 cm, surface application of the required fertilizers are to be applied between 30-60 cm distance from the main trunk under conventional system of irrigation. Such spot application of fertilizers often leads to mismatch in meeting the nutrient requirement of the crop as many physical processes such as leaching, runoff, volatilization etc. leads to loss of applied nutrients besides affecting the environment. Fertigation not only supplies nutrients precisely and timely, it also leads to monetary gain and provide ecological safety

by avoiding pollution of ground water resources (Patel and Rajput, 2000).

In Tamil Nadu, a dose of 100:40:140 g NPK tree<sup>-1</sup> year<sup>-1</sup> is generally recommended (Anon, 2004) for cocoa. The tap roots (1.2 m deep) in cocoa acts as physical support and only lateral roots (20 - 30 cm) absorbs the moisture and nutrients. As cocoa is very sensitive to moisture stress and water logging, irrigation should be at its optimum level for better growth. Hence, the present study was aimed to evaluate the fertigation system involving drip, sprinkler irrigation methods; various levels of fertilizers with a comparison on the farmers practice (surface irrigation + soil application of RDF) on physiological parameters of cocoa.

### Materials and Methods

Field experiments were conducted at Department of Spices and Plantation Crops, Tamil Nadu Agricultural University, Coimbatore during January 2010 to December 2011 to find out the effect of fertigation on physiological parameters in cocoa. The age of the cocoa trees was six years which were intercropped with coconut of 30 years old. Cocoa was spaced at 3 x 3 m between the two rows of coconut. Besides, one cocoa plant was planted in between two coconut trees within the coconut row. The population of cocoa trees maintained as 500 plants per ha.

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The drip line was laid out as per the spacing of cocoa trees *i.e.* 3 x 3 m. For each tree in case of drip irrigation, two drippers were installed @ 8 lph dripper<sup>-1</sup>. Two half sub circle micro sprinklers were installed per tree @ 60 lph micro sprinkler<sup>-1</sup> to cover the entire basin. The micro sprinkler type was half sub circle with a height of 30 cm and it sprinkled an area of 60 cm. A venturi assembly was used for mixing fertilizer with irrigation water.

The experiment was laid out in Randomized Block Design (RBD) with thirteen treatments replicated thrice. The treatments include T<sub>1</sub> - 100 % of RDF as surface application (100:40:140 g NPK plant<sup>-1</sup> year<sup>-1</sup>) with flood irrigation (Control), T<sub>2</sub> - 75 % RDF as WSF through fertigation by drip irrigation, T<sub>3</sub> - 100 % RDF as WSF through fertigation by drip irrigation, T<sub>4</sub> - 125 % RDF as WSF through fertigation by drip irrigation, T<sub>5</sub> - 75 % RDF as straight fertilizers through fertigation by drip irrigation, T<sub>6</sub> - 100 % RDF as straight fertilizers through fertigation by drip irrigation, T<sub>7</sub> - 125 % RDF as straight fertilizers through fertigation by drip irrigation, T<sub>8</sub> - 75 % RDF as WSF through fertigation by micro sprinkler irrigation, T<sub>9</sub> - 100 % RDF as WSF through fertigation by micro sprinkler irrigation, T<sub>10</sub> - 125 % RDF as WSF through fertigation by micro sprinkler irrigation, T<sub>11</sub> - 75 % RDF as straight fertilizers through fertigation by micro sprinkler irrigation, T<sub>12</sub> - 100 % RDF as straight fertilizers through fertigation by micro sprinkler irrigation and T<sub>13</sub> - 125 % RDF as straight fertilizers through fertigation by micro sprinkler irrigation.

For surface application and irrigation (T<sub>1</sub>), an annual application of 100 g N, 40 g P<sub>2</sub>O<sub>5</sub> and 140 g K<sub>2</sub>O per tree per year in two split doses was made as per recommendation. The fertilizers were applied in two equal splits, the first dose in first week of April and the second dose in first week of September. Surface irrigation was done once in seven days interval. For drip and micro sprinkler treatments (T<sub>2</sub> to T<sub>13</sub>), the fertilizers were applied through drip and micro sprinkler irrigation system (fertigation) at weekly intervals and the irrigation was resorted once in a day (20 litres tree<sup>-1</sup> day<sup>-1</sup>).

For individual leaf measurements, the fourth leaf from the apex of matured branch was taken as indicator leaf (15 leaves per tree) as this is the most active part of the cocoa plant that absorbs nutrient from the soil (Alex Alan *et al.*, 2007). The leaf samples were analyzed as per standard procedures suggested by Pearce *et al.* (1968) for specific leaf weight, Yoshida *et al.* (1971) for total chlorophyll, Nicholas *et al.* (1976) for nitrate reductase, Parthasarathi *et al.* (1970) for IAA oxidase, Perur (1962) for peroxidase, Somogyi (1952) and Piper (1966) for C/N ratio in leaves, Sathiamoorthy (1973) for stomatal characters.

## Results and Discussion

The physiological attributes are closely related to yield and quality parameters. Pooled mean values of 2010 and 2011 showed that, the leaf area was more in T<sub>4</sub> (325.4 cm<sup>2</sup>) (Table 1). In coffee, nutrient

**Table 1. Effect of drip and micro sprinkler fertigation on leaf area leaf<sup>-1</sup> (cm<sup>2</sup>) of cocoa at various growth stages**

Treatment	2010				2011					Pooled analysis (2010 and 2011)	
	1 <sup>st</sup> season		2 <sup>nd</sup> season		Mean	1 <sup>st</sup> season		2 <sup>nd</sup> season			
	Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		
T <sub>1</sub> -100 % RDF + surface application + flood irrigation (control)	282.6	300.7	296.3	296.8	294.1	286.3	300.7	274.4	288.9	287.6	290.9
T <sub>2</sub> - 75 % RDF as WSF + Drip	303.7	318.6	299.0	308.2	307.4	311.2	320.7	300.8	318.5	312.8	310.1
T <sub>3</sub> - 100 % RDF as WSF + Drip	322.0	322.3	320.7	316.1	320.3	300.9	319.9	319.6	309.7	312.5	316.4
T <sub>4</sub> - 125 % RDF as WSF + Drip	342.3	329.9	325.7	327.4	331.3	306.5	328.4	322.6	320.1	319.4	325.4
T <sub>5</sub> - 75 % RDF as SF + Drip	299.6	310.2	304.4	311.8	306.5	314.5	314.4	309.1	312.8	312.7	309.6
T <sub>6</sub> - 100 % RDF as SF + Drip	334.6	314.8	299.9	300.4	312.4	310.7	312.6	316.3	300.0	309.9	311.2
T <sub>7</sub> - 125 % RDF as SF + Drip	330.9	318.4	322.7	320.8	323.2	315.7	304.2	298.7	313.2	307.9	315.6
T <sub>8</sub> - 75 % RDF as WSF + MS	291.7	310.4	319.8	300.6	305.6	296.8	308.8	291.9	297.4	298.7	302.2
T <sub>9</sub> - 100 % RDF as WSF + MS	326.3	305.9	310.2	306.4	312.2	307.4	313.8	303.1	290.6	303.8	307.9
T <sub>10</sub> - 125 % RDF as WSF + MS	320.5	320.0	309.8	319.0	317.3	320.5	320.1	314.1	289.6	311.1	314.2
T <sub>11</sub> - 75 % RDF as SF + MS	289.0	311.9	299.9	288.9	297.5	317.3	310.6	319.6	308.4	313.9	305.7
T <sub>12</sub> - 100 % RDF as SF + MS	281.4	318.6	314.7	313.2	306.9	309.6	301.1	285.1	317.7	303.3	305.2
T <sub>13</sub> - 125 % RDF as SF + MS	309.5	316.9	289.4	310.8	306.6	299.5	314.8	299.4	310.7	306.1	306.4
SEd	5.3	5.2	5.1	4.9		5.0	4.9	4.9	4.9		4.9
CD (0.05)	10.9	10.4	10.4	10.3		10.3	10.1	10.3	10.2		10.2
CD (0.01)	14.8	14.0	14.2	14.0		14.1	13.8	14.0	13.9		13.9

RDF - Recommended Dose of Fertilizers, WSF - Water Soluble Fertilizers, SF - Straight Fertilizers, MS - Micro Sprinkler

availability played the major role for significant increase in leaf area due to N application as opined by Karuthamani (2010).

The specific leaf weight is considered to be a good indicator of the photosynthetic capacity of leaves. It was highest in the plants which received

NPK at 125 per cent level through fertigation using water soluble fertilizer and it was the least in conventional method (Table 2). The increase in specific leaf weight by fertigation could be directly

related to better photosynthetic efficiency by stocking of more number of palisade cells (Shinde and Jadhaw, 1995).

**Table 2. Effect of drip and micro sprinkler fertigation on specific leaf weight (mg cm<sup>-2</sup>) of cocoa at various growth stages**

Treatment	2010					2011					Pooled analysis (2010 and 2011)
	1 <sup>st</sup> season		2 <sup>nd</sup> season		Mean	1 <sup>st</sup> season		2 <sup>nd</sup> season		Mean	
	Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		
T <sub>1</sub> -100 % RDF + surface application + flood irrigation (control)	6.63	5.36	5.68	5.80	5.87	5.68	5.31	5.59	5.51	5.52	5.69
T <sub>2</sub> - 75 % RDF as WSF + Drip	6.51	5.92	6.08	6.14	6.16	6.11	5.69	5.55	5.28	5.66	5.91
T <sub>3</sub> - 100 % RDF as WSF + Drip	6.63	6.34	5.53	6.49	6.25	5.83	4.90	5.59	5.53	5.46	5.85
T <sub>4</sub> - 125 % RDF as WSF + Drip	7.98	6.61	6.83	6.68	7.03	6.16	5.60	5.87	6.09	5.93	6.48
T <sub>5</sub> - 75 % RDF as SF + Drip	6.49	6.27	5.58	5.77	6.03	5.78	5.47	5.47	5.17	5.47	5.75
T <sub>6</sub> - 100 % RDF as SF + Drip	5.78	6.35	5.43	5.94	5.87	5.99	5.25	5.19	5.27	5.43	5.65
T <sub>7</sub> - 125 % RDF as SF + Drip	6.06	6.35	6.35	6.08	6.21	5.44	5.15	5.46	5.31	5.34	5.78
T <sub>8</sub> - 75 % RDF as WSF + MS	5.86	6.08	5.79	5.76	5.87	5.81	5.22	5.59	5.51	5.53	5.70
T <sub>9</sub> - 100 % RDF as WSF + MS	7.21	5.35	6.48	6.08	6.28	6.10	5.19	5.83	5.64	5.69	5.99
T <sub>10</sub> - 125 % RDF as WSF + MS	6.27	5.59	5.88	5.96	5.92	6.28	5.25	5.21	5.52	5.57	5.75
T <sub>11</sub> - 75 % RDF as SF + MS	6.69	5.84	5.93	6.24	6.18	5.66	5.51	5.64	5.27	5.52	5.85
T <sub>12</sub> - 100 % RDF as SF + MS	7.20	5.81	6.02	6.09	6.28	6.09	5.43	6.04	5.39	5.74	6.01
T <sub>13</sub> - 125 % RDF as SF + MS	6.68	5.68	6.45	6.44	6.31	6.20	5.11	5.34	5.25	5.47	5.89
SEd	0.12	0.09	0.11	0.10		0.09	0.09	0.09	0.09		0.09
CD (0.05)	0.24	0.20	0.22	0.21		0.20	0.18	0.19	0.18		0.19
CD (0.01)	0.33	0.28	0.30	0.29		0.27	0.24	0.26	0.24		0.27

RDF - Recommended Dose of Fertilizers, WSF - Water Soluble Fertilizers, SF - Straight Fertilizers, MS - Micro Sprinkler

The leaf chlorophyll content which is the key factor in determining the rate of photosynthesis is also considered as an index of the metabolic efficiency of plants. Among the fertigation levels experimented, application of 125 per cent RDF as WSF through fertigation by drip irrigation (T<sub>4</sub>) registered the highest total chlorophyll content (2.14 and 2.11 mg g<sup>-1</sup>) during

first season of 2010 and 2.11 and 1.92 mg g<sup>-1</sup> during first season of 2011 at pod set stage and pod maturity and harvest stage respectively. In second season of 2010, T<sub>3</sub> registered the highest total chlorophyll content (2.10 and 2.10 mg g<sup>-1</sup>) in both the stages (Table 3). The concentration of chlorophyll at pod set stage was more when compared to other

**Table 3. Effect of drip and micro sprinkler fertigation on total chlorophyll (mg g<sup>-1</sup>) of cocoa at various growth stages**

Treatment	2010					2011					Pooled analysis (2010 and 2011)
	1 <sup>st</sup> season		2 <sup>nd</sup> season		Mean	1 <sup>st</sup> season		2 <sup>nd</sup> season		Mean	
	Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		
T <sub>1</sub> -100 % RDF + surface application + flood irrigation (control)	1.60	1.70	1.64	1.61	1.64	1.73	1.62	1.69	1.64	1.67	1.66
T <sub>2</sub> - 75 % RDF as WSF + Drip	1.73	1.82	1.72	1.89	1.79	1.79	1.74	1.87	1.80	1.80	1.79
T <sub>3</sub> - 100 % RDF as WSF + Drip	1.82	2.06	2.10	2.10	2.02	1.83	1.86	2.01	1.91	1.91	1.96
T <sub>4</sub> - 125 % RDF as WSF + Drip	2.14	2.11	2.09	1.83	2.04	2.11	1.92	1.91	2.00	1.98	2.01
T <sub>5</sub> - 75 % RDF as SF + Drip	1.70	1.84	2.02	1.83	1.85	1.89	1.80	1.83	1.79	1.83	1.84
T <sub>6</sub> - 100 % RDF as SF + Drip	1.96	2.00	1.93	1.97	1.97	2.01	1.79	1.88	1.81	1.87	1.92
T <sub>7</sub> - 125 % RDF as SF + Drip	2.06	1.90	1.89	2.03	1.97	1.94	1.83	1.91	1.87	1.89	1.93
T <sub>8</sub> - 75 % RDF as WSF + MS	1.75	1.82	1.79	1.88	1.81	1.79	1.73	1.79	1.78	1.78	1.79
T <sub>9</sub> - 100 % RDF as WSF + MS	1.81	1.95	1.99	1.74	1.87	1.81	1.79	1.89	1.76	1.81	1.84
T <sub>10</sub> - 125 % RDF as WSF + MS	2.02	1.99	2.04	1.91	1.99	1.84	1.84	1.86	1.80	1.84	1.91
T <sub>11</sub> - 75 % RDF as SF + MS	1.77	1.87	1.82	1.79	1.81	1.77	1.69	1.77	1.73	1.74	1.78
T <sub>12</sub> - 100 % RDF as SF + MS	1.93	1.92	1.87	1.80	1.88	1.98	1.73	1.82	1.79	1.83	1.86
T <sub>13</sub> - 125 % RDF as SF + MS	1.87	1.95	1.98	1.69	1.88	1.82	1.78	1.87	1.82	1.82	1.85
SEd	0.03	0.03	0.03	0.03		0.03	0.03	0.03	0.03		0.03
CD (0.05)	0.07	0.07	0.07	0.06		0.06	0.06	0.06	0.06		0.06
CD (0.01)	0.09	0.09	0.09	0.09		0.09	0.08	0.08	0.08		0.09

RDF - Recommended Dose of Fertilizers, WSF - Water Soluble Fertilizers, SF - Straight Fertilizers, MS - Micro Sprinkler

stages and the increase in chlorophyll may be due to improved vegetative growth as a result of better water absorption and uptake of nutrients which have close association with chlorophyll biosynthesis. This finding is in accordance with earlier reports of Karthik (2011) in mango.

Application of 125 per cent RDF as WSF through fertigation by drip irrigation (T<sub>4</sub>) recorded the highest nitrate reductase activity in all stages studied during both seasons as well as in both the years (1.35, 1.89, 1.63 and 1.55  $\mu\text{g of NO}_2 \text{ g}^{-1} \text{ h}^{-1}$  during 2010 and 1.59, 1.51, 1.59 and 1.47  $\mu\text{g of NO}_2 \text{ g}^{-1} \text{ h}^{-1}$  during

**Table 4. Effect of drip and micro sprinkler fertigation on Nitrate Reductase (NRase) ( $\mu\text{g of NO}_2 \text{ g}^{-1} \text{ h}^{-1}$ ) of cocoa at various growth stages**

Treatment	2010					2011					Pooled analysis (2010 and 2011)
	1 <sup>st</sup> season		2 <sup>nd</sup> season		Mean	1 <sup>st</sup> season		2 <sup>nd</sup> season		Mean	
	Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		
T <sub>1</sub> -100 % RDF + surface application + flood irrigation (control)	0.86	0.81	1.10	1.04	0.95	0.93	0.87	0.99	1.01	0.95	0.95
T <sub>2</sub> - 75 % RDF as WSF + Drip	0.99	1.06	1.14	1.27	1.11	1.09	1.23	1.31	1.23	1.22	1.17
T <sub>3</sub> - 100 % RDF as WSF + Drip	1.08	1.65	1.60	1.49	1.46	1.54	1.44	1.45	1.45	1.47	1.46
T <sub>4</sub> - 125 % RDF as WSF + Drip	1.35	1.89	1.63	1.55	1.61	1.59	1.51	1.59	1.47	1.54	1.57
T <sub>5</sub> - 75 % RDF as SF + Drip	0.91	1.23	1.25	1.46	1.21	1.41	1.27	1.39	1.39	1.37	1.29
T <sub>6</sub> - 100 % RDF as SF + Drip	1.00	1.68	1.58	1.21	1.37	1.33	1.40	1.50	1.33	1.39	1.38
T <sub>7</sub> - 125 % RDF as SF + Drip	1.24	1.18	1.36	1.25	1.26	1.35	1.37	1.52	1.40	1.41	1.34
T <sub>8</sub> - 75 % RDF as WSF + MS	1.15	1.50	1.34	1.47	1.37	1.47	1.37	1.23	1.36	1.36	1.36
T <sub>9</sub> - 100 % RDF as WSF + MS	1.00	1.38	1.48	1.39	1.32	1.41	1.39	1.49	1.29	1.40	1.36
T <sub>10</sub> - 125 % RDF as WSF + MS	0.99	1.49	1.40	1.43	1.33	1.36	1.40	1.42	1.39	1.39	1.36
T <sub>11</sub> - 75 % RDF as SF + MS	0.90	1.09	1.51	1.24	1.19	0.98	0.94	1.11	1.21	1.06	1.12
T <sub>12</sub> - 100 % RDF as SF + MS	0.92	1.34	1.38	1.18	1.20	1.07	1.09	1.33	1.38	1.22	1.21
T <sub>13</sub> - 125 % RDF as SF + MS	1.14	1.52	1.29	1.30	1.31	1.35	1.11	1.40	1.39	1.31	1.31
SEd	0.02	0.03	0.03	0.02		0.03	0.03	0.03	0.02		0.02
CD (0.05)	0.04	0.07	0.06	0.05		0.06	0.05	0.05	0.05		0.05
CD (0.01)	0.06	0.09	0.08	0.07		0.08	0.07	0.07	0.07		0.07

RDF - Recommended Dose of Fertilizers, WSF - Water Soluble Fertilizers, SF - Straight Fertilizers, MS - Micro Sprinkler

2011 at pod set stage and pod maturity and harvest stage) (Table 4). In drip fertigation system, application of nutrients and water at frequent time interval maintains the soil moisture preventing the

trees from soil moisture stress thus resulting in a physiologically active state and increased nitrate reductase activity.

Among the growth hormones, Indole acetic acid

**Table 5. Effect of drip and micro sprinkler fertigation on IAA oxidase ( $\mu\text{g g}^{-1}\text{h}^{-1}$ ) of cocoa at various growth stages**

Treatment	2010					2011					Pooled analysis (2010 and 2011)
	1 <sup>st</sup> season		2 <sup>nd</sup> season		Mean	1 <sup>st</sup> season		2 <sup>nd</sup> season		Mean	
	Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		
T <sub>1</sub> -100 % RDF + surface application + flood irrigation (control)	25.4	29.8	30.3	28.8	28.6	30.3	27.7	29.4	29.8	29.3	28.9
T <sub>2</sub> - 75 % RDF as WSF + Drip	17.6	22.5	21.1	22.9	21.0	20.3	21.7	21.5	24.8	22.1	21.6
T <sub>3</sub> - 100 % RDF as WSF + Drip	19.9	20.6	24.6	20.0	21.3	21.7	23.4	25.3	21.6	22.9	22.2
T <sub>4</sub> - 125 % RDF as WSF + Drip	17.1	19.5	18.3	19.9	18.7	18.9	21.3	20.3	19.9	20.1	19.4
T <sub>5</sub> - 75 % RDF as SF + Drip	18.0	23.1	18.4	22.6	20.5	21.7	21.4	24.0	23.4	22.6	21.6
T <sub>6</sub> - 100 % RDF as SF + Drip	17.1	19.9	22.3	20.4	19.9	25.3	22.9	19.7	18.7	21.7	20.8
T <sub>7</sub> - 125 % RDF as SF + Drip	18.5	25.3	23.5	23.1	22.6	19.8	23.3	23.3	21.2	21.9	22.2
T <sub>8</sub> - 75 % RDF as WSF + MS	21.8	25.2	22.7	24.7	23.6	20.4	22.4	23.7	22.0	22.1	22.9
T <sub>9</sub> - 100 % RDF as WSF + MS	19.9	23.9	24.9	24.9	23.4	22.6	22.0	24.6	21.5	22.7	23.1
T <sub>10</sub> - 125 % RDF as WSF + MS	23.9	28.2	29.7	27.6	27.3	25.9	25.8	28.7	28.6	27.2	27.3
T <sub>11</sub> - 75 % RDF as SF + MS	22.0	25.0	27.4	26.7	25.3	29.8	26.9	22.9	25.0	26.2	25.7
T <sub>12</sub> - 100 % RDF as SF + MS	24.8	29.2	28.5	28.8	27.8	28.1	23.7	24.4	24.9	25.3	26.5
T <sub>13</sub> - 125 % RDF as SF + MS	21.8	25.2	22.7	24.7	23.6	30.2	25.4	25.1	27.2	26.9	25.3
SEd	0.42	0.52	0.52	0.49		0.54	0.44	0.45	0.48		0.46
CD (0.05)	0.87	1.07	1.08	1.01		1.12	0.91	0.93	0.98		0.96
CD (0.01)	1.19	1.46	1.47	1.37		1.53	1.24	1.27	1.34		1.30

RDF - Recommended Dose of Fertilizers, WSF - Water Soluble Fertilizers, SF - Straight Fertilizers, MS - Micro Sprinkler

(IAA) involves in apical dominance and initiation of vegetative and flower buds and IAA oxidase is the enzyme responsible for destruction of auxin through the process of oxidation. The amino acid tryptophan and zinc level in leaves influence the IAA. Therefore higher activity of IAA oxidase causes reduction in auxin content causing decreased growth of trees.

The mean values of the activity across the two seasons indicated the lowest IAA oxidase activity of 18.7 and 20.1  $\mu\text{g g}^{-1} \text{h}^{-1}$  in 2010 and 2011 in T<sub>4</sub> (Table 5). The IAA oxidase activity was more in pod maturity and harvest stage when compared to pod set stage.

**Table 6. Effect of drip and micro sprinkler fertigation on peroxidase activity (D430 nm g<sup>-1</sup>h<sup>-1</sup>) of cocoa at various growth stages**

Treatment	2010					2011					Pooled analysis (2010 and 2011)
	1 <sup>st</sup> season		2 <sup>nd</sup> season		Mean	1 <sup>st</sup> season		2 <sup>nd</sup> season		Mean	
	Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		
T <sub>1</sub> -100 % RDF + surface application + flood irrigation (control)	0.63	0.61	0.71	0.69	0.66	0.65	0.63	0.67	0.65	0.65	0.65
T <sub>2</sub> - 75 % RDF as WSF + Drip	0.79	0.84	0.78	0.81	0.81	0.72	0.72	0.79	0.78	0.75	0.78
T <sub>3</sub> - 100 % RDF as WSF + Drip	0.83	0.90	0.92	0.82	0.87	0.79	0.76	0.93	0.89	0.84	0.86
T <sub>4</sub> - 125 % RDF as WSF + Drip	0.89	0.97	0.90	0.88	0.91	0.91	0.80	0.88	0.91	0.88	0.89
T <sub>5</sub> - 75 % RDF as SF + Drip	0.68	0.78	0.86	0.81	0.78	0.79	0.71	0.76	0.81	0.77	0.78
T <sub>6</sub> - 100 % RDF as SF + Drip	0.77	0.93	0.89	0.82	0.85	0.76	0.75	0.84	0.85	0.80	0.83
T <sub>7</sub> - 125 % RDF as SF + Drip	0.79	0.72	0.82	0.81	0.79	0.83	0.77	0.81	0.87	0.82	0.81
T <sub>8</sub> - 75 % RDF as WSF + MS	0.76	0.69	0.74	0.76	0.74	0.81	0.74	0.76	0.69	0.75	0.75
T <sub>9</sub> - 100 % RDF as WSF + MS	0.63	0.75	0.72	0.81	0.73	0.76	0.79	0.80	0.75	0.77	0.75
T <sub>10</sub> - 125 % RDF as WSF + MS	0.66	0.69	0.77	0.72	0.71	0.85	0.77	0.84	0.79	0.81	0.76
T <sub>11</sub> - 75 % RDF as SF + MS	0.79	0.83	0.74	0.76	0.78	0.83	0.69	0.72	0.69	0.74	0.76
T <sub>12</sub> - 100 % RDF as SF + MS	0.80	0.80	0.79	0.82	0.81	0.77	0.73	0.75	0.79	0.76	0.78
T <sub>13</sub> - 125 % RDF as SF + MS	0.73	0.81	0.74	0.79	0.77	0.80	0.76	0.82	0.83	0.80	0.78
SEd	0.01	0.02	0.01	0.01		0.01	0.01	0.01	0.01		0.01
CD (0.05)	0.03	0.03	0.03	0.03		0.03	0.03	0.03	0.03		0.03
CD (0.01)	0.04	0.04	0.04	0.04		0.04	0.03	0.04	0.04		0.04

RDF - Recommended Dose of Fertilizers, WSF - Water Soluble Fertilizers, SF - Straight Fertilizers, MS - Micro Sprinkler

Application of 125 per cent recommended NPK as WSF through drip fertigation significantly increased the peroxidase activity (Table 6). Peroxidase enzyme is ubiquitous in plants at the

site of cell wall and, it participates in lignin biosynthesis. It scavenges the excess amount of oxygen species hydrogen peroxide formed in plant cells under normal and stress conditions (Syherri

**Table 7. Effect of drip and micro sprinkler fertigation on C/N ratio in leaf of cocoa at various growth stages**

Treatment	2010					2011					Pooled analysis (2010 and 2011)
	1 <sup>st</sup> season		2 <sup>nd</sup> season		Mean	1 <sup>st</sup> season		2 <sup>nd</sup> season		Mean	
	Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		Pod set stage	Pod maturity and harvest stage	Pod set stage	Pod maturity and harvest stage		
T <sub>1</sub> -100 % RDF + surface application + flood irrigation (control)	12.8	10.9	12.1	9.30	11.3	9.3	8.5	10.3	9.9	9.4	10.4
T <sub>2</sub> - 75 % RDF as WSF + Drip	15.6	14.1	15.4	12.7	14.5	14.5	12.3	16.0	13.7	14.1	14.3
T <sub>3</sub> - 100 % RDF as WSF + Drip	14.2	13.5	15.7	12.5	13.9	15.3	12.4	15.9	13.9	14.4	14.2
T <sub>4</sub> - 125 % RDF as WSF + Drip	15.6	13.8	15.6	12.9	14.5	15.7	13.0	16.5	13.7	14.7	14.6
T <sub>5</sub> - 75 % RDF as SF + Drip	13.9	15.2	14.4	11.7	13.8	14.3	12.2	17.0	14.1	14.4	14.1
T <sub>6</sub> - 100 % RDF as SF + Drip	15.3	13.4	15.5	13.1	14.3	15.6	12.2	16.0	12.7	14.1	14.2
T <sub>7</sub> - 125 % RDF as SF + Drip	15.4	13.6	15.2	13.3	14.4	14.7	12.9	16.6	13.8	14.5	14.4
T <sub>8</sub> - 75 % RDF as WSF + MS	14.7	13.3	14.9	11.4	13.6	14.7	12.1	16.6	12.8	14.1	13.8
T <sub>9</sub> - 100 % RDF as WSF + MS	14.4	13.6	13.9	11.8	13.4	13.5	12.5	16.2	13.3	13.9	13.7
T <sub>10</sub> - 125 % RDF as WSF + MS	14.9	13.8	14.7	12.5	14.0	16.0	12.6	16.5	12.9	14.5	14.3
T <sub>11</sub> - 75 % RDF as SF + MS	14.3	13.9	13.8	11.5	13.4	14.0	12.1	16.2	12.4	13.7	13.6
T <sub>12</sub> - 100 % RDF as SF + MS	14.2	13.9	14.6	12.6	13.9	14.7	12.1	16.8	13.1	14.2	14.0
T <sub>13</sub> - 125 % RDF as SF + MS	14.8	13.2	15.4	11.8	13.8	14.8	12.6	16.9	13.5	14.5	14.1
SEd	0.25	0.21	0.24	0.20		0.24	0.20	0.26	0.22		0.23
CD (0.05)	0.51	0.44	0.49	0.42		0.49	0.41	0.55	0.46		0.46
CD (0.01)	0.69	0.59	0.67	0.57		0.67	0.57	0.74	0.62		0.63

RDF - Recommended Dose of Fertilizers, WSF - Water Soluble Fertilizers, SF - Straight Fertilizers, MS - Micro Sprinkler

et al., 1993). In addition, generation of reactive oxygen species might be responsible for most of the damages caused to cellular compartments. Under stress conditions, detoxifying enzymes like peroxidase and catalase were activated to correct the adverse effects of stress and regulate the metabolic and physiological processes (Sivakumar, 2007).

The shoots with higher starch and C : N ratio (carbohydrate: nitrogen) favour flower bud initiation. The results of the present study revealed that C : N

ratio in leaf was more in pod set stage and reduced at pod maturity and harvest stages. Application of the recommended NPK through conventional method (control) registered the lowest C : N ratio (Table 7). This would have been probably due to inadequate supply of nutrients, which would have substantially reduced the efficiency of trees to convert solar energy into assimilates. This condition might have caused excessive release of electrons from the chloroplast and in turn, the formation of highly toxic 'reactive oxygen species' (Cakmak, 2002).

**Table 8. Effect of drip and micro sprinkler fertigation on stomatal characters in leaf at 40 X**

Treatment	Count (mm <sup>2</sup> )			Length (Microns)			Breadth (Microns)			Size (mm <sup>2</sup> )		
	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
T <sub>1</sub> -100 % RDF + surface application + flood irrigation (control)	164.4	161.9	163.1	14.3	14.2	14.3	11.0	11.1	11.1	157.6	157.8	157.7
T <sub>2</sub> - 75 % RDF as WSF + Drip	173.4	168.6	170.9	16.1	15.4	15.7	12.1	13.1	12.6	194.6	201.2	197.9
T <sub>3</sub> - 100 % RDF as WSF + Drip	170.6	170.7	170.7	15.9	16.1	16.0	13.5	11.9	12.7	222.9	212.1	217.5
T <sub>4</sub> - 125 % RDF as WSF + Drip	174.9	176.3	175.6	16.8	17.8	17.3	13.9	13.8	13.9	223.0	228.5	225.8
T <sub>5</sub> - 75 % RDF as SF + Drip	168.7	173.2	170.9	15.3	16.1	15.7	12.2	11.9	12.1	186.9	193.4	190.2
T <sub>6</sub> - 100 % RDF as SF + Drip	171.4	169.3	170.3	16.6	17.0	16.8	11.9	13.4	12.7	196.9	221.2	209.1
T <sub>7</sub> - 125 % RDF as SF + Drip	176.5	179.6	178.0	16.7	17.0	16.8	12.2	12.8	12.5	208.6	196.8	202.7
T <sub>8</sub> - 75 % RDF as WSF + MS	166.9	176.0	171.5	14.6	16.3	15.5	11.5	11.1	11.3	168.2	181.1	174.6
T <sub>9</sub> - 100 % RDF as WSF + MS	170.2	171.9	171.1	15.3	16.0	15.7	13.0	11.8	12.4	199.4	188.5	193.9
T <sub>10</sub> - 125 % RDF as WSF + MS	171.4	162.3	166.9	16.2	14.9	15.6	12.7	12.0	12.4	206.9	178.7	192.8
T <sub>11</sub> - 75 % RDF as SF + MS	168.7	172.6	170.6	15.9	15.3	15.6	11.2	13.5	12.4	178.4	207.1	192.8
T <sub>12</sub> - 100 % RDF as SF + MS	164.9	168.2	166.6	15.3	14.9	15.1	12.4	13.0	12.7	190.0	193.9	191.9
T <sub>13</sub> - 125 % RDF as SF + MS	165.9	167.1	166.5	15.6	16.2	15.9	12.1	11.4	11.7	188.1	184.7	186.4
SEd	2.72	2.72		0.26	0.26		0.21	0.21		3.54	3.51	
CD (0.05)	5.62	5.62		0.54	0.54		0.43	0.44		7.31	7.24	
CD (0.01)	7.66	7.65		0.74	0.74		0.58	0.60		9.96	9.87	

RDF - Recommended Dose of Fertilizers, WSF - Water Soluble Fertilizers, SF - Straight Fertilizers, MS - Micro Sprinkler

The number of stomata was observed more in T<sub>7</sub> (176.5 and 179.6 per mm<sup>2</sup>) which was on par with the treatment T<sub>4</sub>. The stomatal length and breadth was highest in T<sub>4</sub> (16.8 and 17.8 microns; 13.9 and 13.8 microns) during 2010 and 2011 respectively. The treatment T<sub>4</sub> registered the maximum size of stomata (223.0 and 228.5 mm<sup>2</sup>) during 2010 and 2011 (Table 8). Increase in stomatal number will lead to increased influx of CO<sub>2</sub> and efflux of H<sub>2</sub>O from plant cells. Hence, the rate of photosynthesis is high which is positively correlated to the yield.

The experimental results clearly demonstrates that, fertigated plants, especially with water soluble fertilizers were found to be in a better physiological state at different stages of crop growth when compared to plants fertilized in the conventional manner. Besides the nutrient forms and mode of application, the constant optimal moisture availability due to the drip system in the fertigation treatments could have caused functional changes in the plant.

### Conclusion

Studies taken up in fertigation with cocoa indicated that, the treatment T<sub>4</sub> (125 % RDF as water

soluble fertilizers through fertigation by drip irrigation (125:50:175 g NPK plant<sup>-1</sup> year<sup>-1</sup>)) can remarkably improve the physiological parameters and in turn yield.

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