Int. J. Indust. Entomol. Vol. 8, No. 1, 2004, pp. 1~15

[Review]

International Journal of *Industrial Entomology*

Nutritional Disorders, Analytical Diagnosis and Nutrient Guide for Mulberry, *Morus indica* L.

B. K. Singhal*, S. Chakraborti[1], Mala V. Rajan[2] and T. Thippeswamy[2]

Regional Sericultural Research Station, Central Silk Board, Miran Sahib, Jammu - 181 101, India.
[1]Regional Sericultural Research Station, Kalimpong, West Bengal, India.
[2]Central Sericultural Research and Training Institute, Mysore - 570 008, India.

(Received 10 October 2003; Accepted 12 January 2004)

Due to recent scientific innovations in mulberry cultivation, leaf yield has been increased manifold. However, with successive leaf harvest, a quantum drop in leaf yield and quality has been noted. This inturn has affected the silkworm rearing and farmers suffered by the frequent crop failures. This is mainly due to nutrient deficiencies in mulberry leaf. Moreover, no complete information is available about hunger signs of nutritional disorders, analytical diagnosis and critical levels of nutrients required. The present paper, thus, may serve as an important nutrient guide for identification of hunger signs, leaf nutrients status under deficiency and critical levels of the elements namely N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn requirements for higher leaf yield and quality. The leaf nutrient status provided may help chemist for correcting the soil status. Besides, an integration of mulberry intercropping with legumes and applications of neem and castor oil cakes, VA-mycorrhizal inoculation, biofertilizer and vermicompost are suggested as integrated nutrient management for sustainable sericulture industry. Based on the information described in this paper, a model needs to be framed for maintaining continuous supply of nutrients to obtain desired quantity and quality of mulberry leaf for successful silkworm cocoon crop and increasing overall silk productivity.

Key words: Mulberry, Mineral nutrition, Hunger signs, Analytical diagnosis, Nutrient guide, Integrated nutrient management

*To whom correspondence should be addressed.
Regional Sericultural Research Station, Miran Sahib, Jammu - 181 101, Jammu and Kashmir, India. Tel: 91-01923-263339; Fax: 91-01923-263339; E-mail: bksinghalraj@ndiatimes.com

Introduction

Mulberry (*Morus* sp.) is the sole food plant of the silkworms (*Bombyx mori* L). Mulberry silk is known as the most luxurious and bulk of the silk goods produced in the world are made up of mulberry silk. The quantity and quality of silk is directly dependent on the leaf quality, which influences the healthy growth of silkworm larvae and thereby effects overall cocoon production (Singhal and Mala, 1998; Singhal *et al.*, 1999a, b, 2000b, 2001b). In the event of some minor changes in climate and rearing practices, the quality of leaf acts as a buffer and helps in getting a good cocoon crop. The quality mulberry leaf production mainly depends up on the three major factors *viz.*, genotypic potential of the mulberry variety, environmental factors determined by weather (especially water, CO_2 and factors determining energy availability) and nutritional conditions of the soil. Mulberry can grow luxuriantly with quality leaf only when external factors influencing its growth and development are favourable (Singhal *et al.*, 1998). Apart from green houses, changing climatic factors in mulberry garden are not much possible. Similarly, the use of substances to modify genetically determined metabolic processes (phytohormones) and increasing yield will be possible on a small scale and for a shorter term. It also cost huge expenses. Thus, apart from mulberry pest and weed control, much emphasis is required on leaf nutrition which is major contributory factor for the successful rearing. Miyashita (1986) clearly indicated that the percentage of different factors responsible for successful cocoon crop are: 38.2% of mulberry leaf, 37.0% of climate, 9.3% of rearing technique, 4.2% of silkworm race and 11.3% of other factors. The full genetic potential of mulberry varieties can be exploited within the constraint posed by site and climate only by maintaining a continuous and adequate supply of water and the minerals necessary for mulberry. The rate of nutrient supply must match to the rate of assimilation. Brown (1979) in this context emphasized that except temperature, water and salinity of the soil, nutrient deficiency and excess are the main factors limiting leaf production and nutrient deficiency can be avoided by well balanced fertilizer application.

In India, productivity of silk per unit of land is very low as compared to that of China which is mainly due to lower leaf yield and poor quality of leaves. Various studies in the past and present on silkworm nutrition have established that it is the quality of leaf that ultimately reflects on growth and development of the silkworm as well as on overall silk production though silkworm seed and breed are also important (Dandin *et al.*, 2003). The quality of leaf has a great influence on the amount of food ingested. Thus, it appears to be a very simple and clear logic, that to boost up the productivity of silk, leaf quality has to be improved. In recent time, with the intensification of mulberry cultivation in India, nutrients deficiency has been observed which limits the mulberry growth and in turn, quality and quantity of mulberry leaf (Singh, 1997). Deficiencies of N, P, K, Mg, S and Mn are reported in intensive sericulture areas of this country by Bongale (1995, 1997) and Bongale *et al.* (1996). Further, Bongale and Lingaiah (1998) have analyzed the soils of about 316 mulberry gardens from the important sericulture areas of Karnataka, which is contributing more than 60% of the country's total silk production and macro and micro-nutrients status recorded by them is presented in Table 1. Soil fertility reported is moderate, however, deficient in organic carbon and Zn. Iron content is low to medium, while Cu and Mn status is medium to high. In this leading state, the deficiency percentage for B, Cu, Fe, Mn and Zn in soil is 32.0, 5.3, 34.9, 17.4 and 72.8%, respectively (Singh, 1999). However, deficiency for Mo is not reported in the soil. Zn deficiency is reported in almost all the states of this country. Subbaswamy *et al.* (2000) assessed that, over the years, there is decrease in cocoon yield with frequent silkworm crop losses which is mainly due to nutrient imbalance between soil and the plant. In this regard, the main causes identified for nutrient deficiencies in mulberry are: inadequate supply of one or more nutrients in the soil, nutrient withdrawals due to continuous mulberry cultivation without corresponding nutrient replacement, change in edaphic factors such as pH value or loss of top soil due to wind and water erosion or soil leveling, unbalanced fertilizers application, increasing yield levels causes higher demand for nutrients, repeated application of one element induces the deficiency for other elements, application of wrong element due to faulty diagnosis, depletion of micro-nutrients in soil due to intensive cultivation or no replenishment, uptaking of one or more nutrients in greater quantity due to mulberry cultivation for 15 to 20 years in the same land which causes decrease in yield, though, other cultivation operations are cared.

The importance of minerals in plant nutrition is recognised universally. It is also fully realised that an increase in crop yield per unit area of land depends upon the mineral nutrition. In general, the average leaf yield of mulberry in developing and tropical countries is low due to low yielding genotypes, drought, diseases and nutrient constraints. Nutritional disorders occur in the same impoverished soil after mulberry cultivation with little or

Table 1. Macro and micro-nutrient status of mulberry soils in a prominent bivoltine seed area of India

Soil status	Primary statistics			Range of values and frequency distribution			
	Mean	S.D.	CV%	1	2	3	4
ph	6.77	2.92	43.19	< 6.3(75)	6.30-7.2(195)	7.3-8.2(45)	> 8.2(1)
EC (mmohs/cm)	0.21	0.12	56.37	< 0.14(115)	0.14-0.28(125)	0.29-0.45(61)	> 0.43(15)
OC (%)	0.45	0.22	47.64	< 0.5(193)	0.50-1.0(120)	> 1.0(3)	-
N (Kg/ha)	365.80	256.50	70.11	< 250(98)	250-500(127)	501-750 (32)	> 750(32)
P (ppm)	23.06	18.01	78.08	< 9(70)	9-22(127)	> 22(119)	-
K (ppm)	121.80	88.20	72.42	< 50(40)	50-120(156)	> 120(120)	-
S (ppm)	29.10	14.81	50.89	< 28(181)	28-56(113)	> 56(17)	-
Zn (ppm)	0.72	0.45	61.83	< 0.45(28)	0.45-0.89(146)	0.90-1.34 (26)	> 1.34(12)
Cu (ppm)	0.84	0.38	45.10	< 0.38(9)	0.38-0.76(110)	0.77-1.14 (43)	> 1.14(50)
Mn (ppm)	20.95	19.03	90.80	< 19(126)	9-38(77)	39-57(4)	> 57(5)
Fe (ppm)	7.49	5.09	68.00	< 5(87)	5-10(72)	11-15(37)	> 15(16)
B (ppm)	1.01	0.95	94.66	< 0.95(123)	0.95-1.9(85)	2.0-2.85(3)	> 2.85(1)

Figures in parentheses are frequency distribution.
Bongale and Lingaiah (1998).

no fertilizers application. As a result of uptake by the crop, large quantities of nutrients are depleted and become less available to mulberry in turn bringing down the leaf yield and quality. In mulberry variety V-1 the nutrient deficiency causes decrease in leaf yield to the extent of 17.89 to 31.59%. The chlorotic leaves suffer with Mn and Fe deficiency (Singhvi *et al.*, 2002a). Singhvi *et al.* (2002b) also reported the losses occur due to nutrient deficiency in mulberry variety S-36 in field. To meet the ever-increasing demand of silk, the desired leaf quality needs to be maintained and to achieve the same, till date no consolidated guide for mulberry nutrition is available. In this direction, based on the detailed studies by us and scattered reports of other workers, a nutrient guide has been consolidated in the present paper to maintain higher leaf yield with quality to keep the sericulture industry highly profitable to the farmers.

Experimental Method

The promising mulberry genotype K-2 was planted by cuttings in wagner pots filled with nutrient-free white granite sand powder under glass house condition at 25 ± 2°C room temperature. The pots were watered with deionized water once in 3 days till 70 days of plantation and then all plants were pruned. Later, hoagland nutrient solution was provided to different treatments by eliminating individual element *viz.*, N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn to induce deficiency of each element separately. The design of the experiment was RBD with 12 replications per element. Hunger signs developed for each element were observed (Singhal *et al.*, 1999b).

Importance of nutrients

In general all elements plays a key role in governing various physiological and bio-chemical functions for plants growth and reproduction. The ideas about their basic role in plants is described in several researchers (Epstein, 1972; Kanwar, 1978; Mengel and Krikby, 1978; Christiansen and Foy, 1979; Millaway and Wiersholm, 1979; Bergmann, 1992; Horst, 1995; Marschner, 1995; Gutierrez, 1997; Rengel, 1999). The elements N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn have also been reported for overall improvement of the silkworms growth, silk production as well as for seed production (Table 2).

Nutritional disorders in mulberry

The mineral nutrition disorders and their effects on various agricultural crops have been worked out extensively (Bergmann, 1992; Horst, 1995; Marschner, 1995; Gutierrez, 1997; Rengel, 1999; Tandon, 2002). In mulberry, till date, no concrete information is available in a consolidated form for hunger signs under mineral nutrition deficiency and overall guide to tackle the nutritional disorders. In this regard, a pictorial guide for hunger signs is summarized below.

A key for identification of hunger signs under nutrient deficiency in mulberry

Nitrogen (N): Yellowing starting from leaf margin spreads throughout and finally whole plant becomes yellow. As a result, leaves fall in pre-mature stage. In acute deficiency, the young leaves gets light greenish tinge, which changes into the complete yellow with age. Terminal growth of the plant is arrested and mulberry growth ceases completely (Fig. 1a).

Phosphorus (P): In younger leaves, chlorosis occur throughout the leaf and irregular lesions are formed below the margins. Scorching is observed in severely affected leaves and dried areas begin to fall apart into pieces. With advancement of deficiency, scorching spreads from margin to the midrib area and fall in pre-mature stage. Plant growth is ceased (Fig. 1b).

Potassium (K): The yellowing of leaf starts from the tips which gradually spreads all around the leaf and leaves become totally yellow. The deficient leaf curls downwards. Lower leaves becomes yellow first and fall in premature stage. Terminal growth of the plant is ceased and shoots and leaves become thin (Fig. 1c).

Calcium (Ca): The deficiency first emerge in young leaves and their shape gets distorted. Necrosis starts in tip and then in the margin of the leaves. Old leaves are affected severely which shows yellowish green mosaic patches. The leaves start falling in pre-mature stage. Plant growth is totally ceased and becomes weak and lodged (Fig. 1d).

Magnesium (Mg): Chlorosis starts in leaves which is gradually intensified in the area between the veins leading to chlorotic stripping in between the veins. Gradually chlorosis passes throughout the leaves which become totally yellow with reddish brown lesions along the margins and in the whole area between the veins. Plant growth in ceased (Fig. 1e).

Sulphur (S): Younger leaves are severely deficient and necrosis starts from margin of the leaf. Brownish oily spots are observed throughout these leaves. Under prolonged deficiency, the older leaves turns into pale yellow and starts falling in pre-mature stage. Overall plant growth gets stunted (Fig. 1f).

Boron (B): Veins and lenticels proliferate and protrudes out which finally kills apical bud in stem. Leaf veins gets cracked (Fig. 1g).

Copper (Cu): Younger leaves are yellow and wilting

Table 2. Effects of different elements in silkworm

Sl. no.	Element	Effect in silkworm rearing	References
1	N	Silkworm growth and cocoon quality is superior	Shankar and Absar (1995); Takagishi *et al.* (1985)
		Higher mature larval weight, larval survivability, effective rate of rearing and cocoon yield	Sannappa *et al.* (2002)
		Feeding mulberry leaf to the silkworm containing five minerals in phosphorus form uses minimum energy for maintenance	Subburathinam *et al.* (1993)
2	P	Increase larval growth, economic characters and fecundity	Subburathinam and Sulochanachetty (1991)
		Occurrence of flacherie disease in silkworms under phosphorus deficiency	Subbaswamy *et al.* (2001)
		Supplementation of potassium nitrate and potassium iodide increase larval and shell weights	Chakraborty and Medda (1978); Subburathinam and Sulochanachetty (1991)
3	K	Potassium iodide at 20 μg/ml concentration incre- ase shell weight, oviposition rate, protein and RNA, DNA content of silkgland	Dasmahapatra *et al.* (1989); Majumdar (1982)
4	Ca	Mulberry leaf enriched with 1% calcium chloride increase the cocoon weight (11.42%), shell weight (16.75%), cocoon/shell ratio (6.70%) and silk proteins (Fibroin by 4.85% and sericin by 9.32%)	Subburathinam *et al.* (1990)
		Feeding behaviour of the newly hatched silkworm larvae is effected by $CaCO_3$	Tsuneyama and Tanaka (2001)
		Increase cocoon yield and shell percentage	Loknath and Shivashankar (1985); Subburathinam *et al.* (1990); Thangavelu and Bania (1990)
5	Mg	Deficiency increases sericin content and decreases fibroin content of the cocoons	Shankar and Shivashankar (1994)
6	S	Deficiency causes reduction in cocoon weight and silk filament length	Radha *et al.* (1988); Shankar *et al.* (1994)
		Sulphur supplementation increases cocoon and shell percentage	Murali *et al.* (2000)
7	B	Boron deficiency decreases 41.5% of silk filament length	Shankar (1997)
		Ferrous ammonium sulphate (1% w/v) fortified mulberry leaf increases silk filament length by 20%	Jayaprakashrao *et al.* (1998)
		30 ppm $CuSO_4$ enriched leaf increases cocoon shell by 15.0%	Magadum *et al.* (1992)
8	Cu	Feeding of Copper with artificial diet effects growth and development of silkworm	Miyoshi *et al.* (1978)
9	Fe	Improve cocoon weight, size, shell percentage and fecundity	Chakraborti *et al.* (1997); Horie *et al.* (1967); Ito and Nimura (1966); Jayaprakashrao *et al.* (1998); Loknath and Shivashankar (1985); Rai *et al.* (2002); Subburathinam *et al.*, (1993); Viswanath and Krishnamoorthy (1982)
10	Mn	Improve silkworm growth, cocoon yield, shell percentage and overall silk yield	Chikkaswamy *et al.* (2000); Horie *et al.* (1967); Ito and Nimura (1966); Loknath and Shivashankar (1985); Viswanath (1979)
11	Zn	Important for reproduction and thus is much useful in grainages for improving seed production	Chakraborti *et al.* (1997)
		At 20 ppm concentration enhancing hatching percentage	Chamundeswari and Radhakrishnaiah (1994)
		Enhancing energetic efficiency and increases silk filament length	Chikkaswamy *et al.* (2000); Horie *et al.* (1967); Horie and Watanabe (1980); Ito and Nimura (1966); Maynard *et al.* (1984)

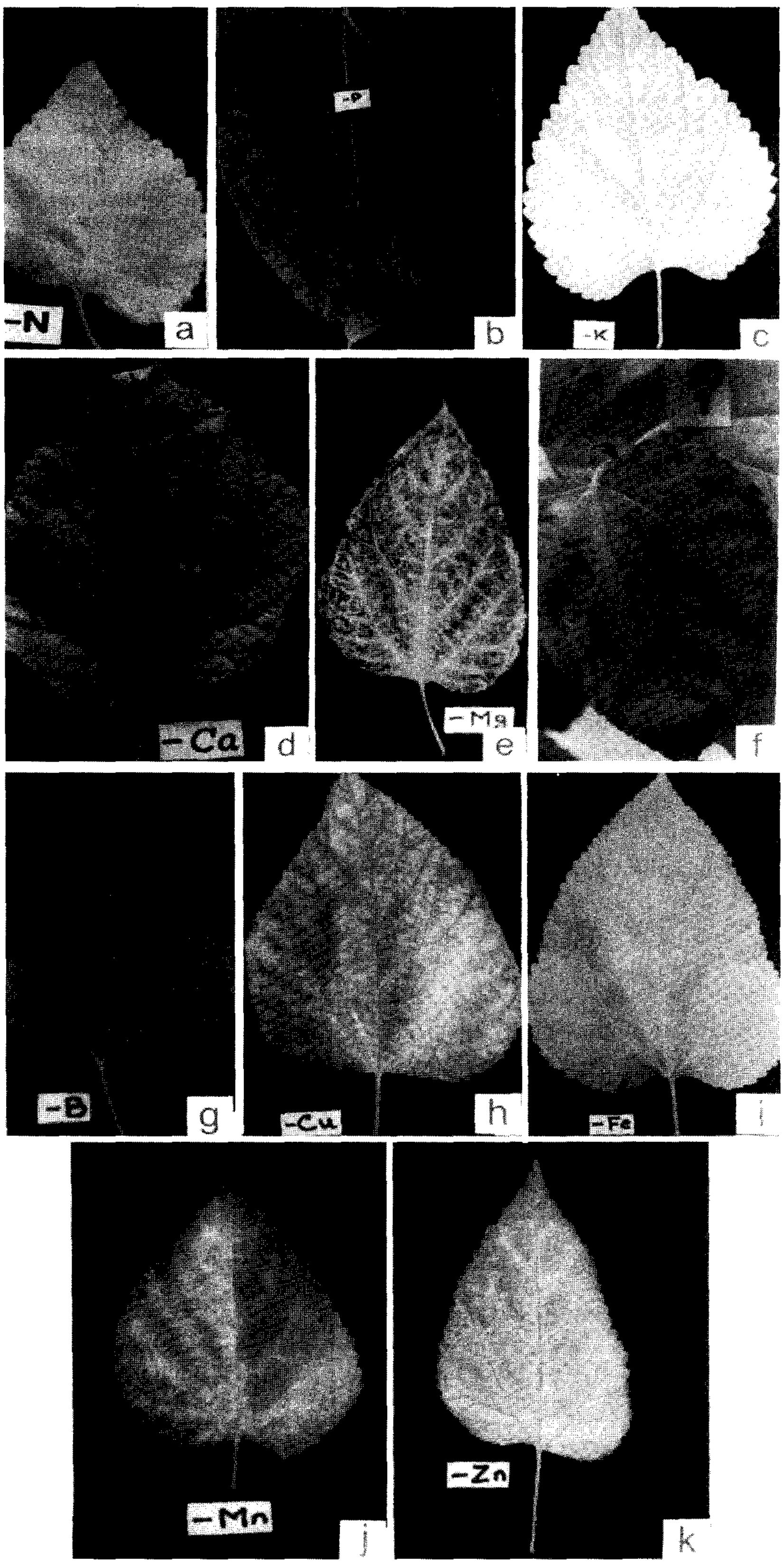

Fig. 1. Nutritional disorders in mulberry. Deficiency symptoms for Nitrogen (a), Phosphorus (b), Potassium (c), Calcium (d), Magnesium (e), Sulphur (f), Boron (g), Copper (h), Iron (i), Manganese (j) and Zinc (k).

starts from tip. Chlorosis is started from the margin of the leaf and is observed in between the veins. The leaf loses its lustre with severe moisture loss causes wilting. Leaves fall in pre-mature stage (Fig. 1h).

Iron (Fe): The chlorosis occur in between the veins which lateron extends to the whole leaf. Gradually chlorosis increases and leaves become golden yellow in colour with dusty look (Fig. 1i).

Manganese (Mn): In younger leaves, chlorosis starts from the margin and spreads toward whole leaf. In mature leaves, yellowish white spots are found throughout the leaf. However, the principle veins as well as the small veins tend to stay green. The interveinal portion becomes chlorotic and plant growth is ceased (Fig. 1j).

Zinc (Zn): Chlorosis develops in the margins and mid veins near the base of the leaf blade. With the intensification of deficiency, the chlorosis extends towards the leaf tip and then turn into yellowish white in between the veins. The veins, veinlets and the portions adjacent to veins remains dark green. Overall plant growth is ceased and becomes weak and lodged (Fig. 1k).

Analytical diagnosis

The leaf analysis is reported as the best method to find out the existing leaf nutrient status for correcting the fertilizers need, below which the yield is limited and above which the use of fertilizer is either toxic or luxuriant as well as not economical. It is most often used in trouble shooting as suggested by Lundegardh (1943), Blamey *et al.* (1987), Bhargava and Chaddha (1988), Singhal *et al.* (1999a, b, 2000b). In this regard, the analytical diagnosis reports for physiological and biochemical changes under nutrient deficiencies in mulberry are summarized below.

The photosynthetic rate is reduced significantly under deficiency of all the elements (Singhal *et al.*, 2000b). Similarly, stomatal conductance, inter cellular CO_2 concentration and transpiration rate are also affected under nutrient deficiencies. Recent research on crop physiology suggests that total biomass production and the yield of different crops depend primarily on photosynthetic CO_2 assimilation (Menon and Srivastava, 1984). In mulberry an indirect correlation has been observed between the photosynthetic rate and the leaf yield. P, K, Fe, Mg and Zn deficiencies causes serious reduction in leaf yield (Singhal *et al.*, 2000a). However, no further reports are available for such work in mulberry.

Chlorophyll 'a', 'b' and total chlorophyll contents are reduced sharply under nutrient deficiency (Table 3). Maximum reduction is observed under the deficiencies of N, S, Cu and Mn with total chlorophyll contents of 0.514, 0.709, 0.633 and 0.605 mg/g of fresh leaf tissue, respectively, as compared to 2.280 mg/g in control. In silkworms, chlorophyll influences their economic characters to a great extent (Shylaja, 1996). Under deficiencies of N, Cu, Zn and Ca, the protein content is reduced to as low as 10.71, 10.84, 11.92 and 12.35%, respectively, as compared to 18.48% in control (Table 4). In mulberry leaf, the protein content has been reported to have a direct correlation with the production efficiency of cocoon shell in silkworm (Machii and Katagiri, 1991). Enrichment of mulberry leaves with protein supplements strongly favoured the larval growth, development and cocoon production in

Table 3. Change in chlorophyll content of mulberry leaf (mg/g fresh leaf tissue) under nutrient deficiency

Nutrient Deficiency	Chlorophyll 'a'	Chlorophyll 'b'	Total Chlorophyll
Control	1.723	0.557	2.280
N	0.356	0.158	0.514
P	0.984	0.391	1.375
K	1.312	0.465	1.777
Ca	0.363	0.375	0.738
Mg	0.817	0.365	1.182
S	0.484	0.225	0.709
Fe	0.918	0.380	1.298
Zn	0.886	0.401	1.287
Cu	0.329	0.304	0.633
Mn	0.431	0.174	0.605
B	1.140	0.421	1.611
CD at 5%	0.006	0.016	0.016

Control = No deficiency for any element (complete solution).

Table 4. Change in protein, ascorbic acid and carotenoid contents of mulberry leaf under nutrient deficiency

Nutrient deficiency	Protein (%)	Ascorbic acid (%)	Carotenoid (mg/g)
Control	18.48	0.224	0.820
N	10.71	0.040	0.260
P	15.24	0.036	0.572
K	17.34	0.048	0.490
Ca	12.35	0.027	0.224
Mg	14.27	0.091	0.512
S	12.87	0.037	0.303
Fe	15.99	0.034	0.554
Zn	11.92	0.037	0.500
Cu	10.84	0.027	0.519
Mn	16.20	0.038	0.325
B	15.76	0.040	0.553
CD at 5%	0.31	0.003	0.006

Control = No deficiency for any element (complete solution).

silkworm (Sunder Raj *et al.*, 2002). The protein supplementation in shoot rearing increases the cocoon yield in silkworms (Manimegalai *et al.*, 2002). Under nutrient deficiency, vitamin 'a' (carotenoids) and vitamin 'c' (ascorbic acid) are also adversely affected. In Cu and Ca deficiency ascorbic acid is decreased to as low as 0.027% as compared to 0.224% in control. Similarly, carotenoid is also very low under deficiencies (0.224 and 0.519 mg/g of fresh leaf tissue under Ca and Cu deficiency, respectively) as compared to in the plants provided with complete solution (0.820 mg/g). Silkworms are totally dependent on mulberry leaf for their ascorbic acid requirement, as it is not synthesized in the silkworms body (Ito, 1961; Ito and Arai, 1965; Datta Gupta *et al.*, 1972; Chakraborti and Singhal, 1996). It provides resistance in silkworms to fight against diseases as well as its presence in leaf increase the overall silk length of the cocoons. Improvement in silkworm economic characters are reported by Dadmal *et al.* (2001) when silkworms are fed with ascorbic acid enriched mulberry leaves. Moreover, it has a phagostimulatory effects. Carotene is also reported to improve the silkworms economic characters (Shylaja, 1996). Gowda (2002) found significant increase in silkworm economic characters by the feeding of Seripro (a powder comprising of proteins, vitamins, carbohydrates, sterols, etc. developed by Ashchem Agrotech Ltd., Bangalore, India) supplemented leaves to the silkworm and reported a great potential of Seripro in commercial sericulture. The elemental composition is also affected under nutrient deficiency (Table 5). Nitrogen deficiency causes a significant reduction in the compositon of all the elements. Zn and Cu contents are reduced heavily under nitrogen deficiency. Among secondary nutrients *viz.*, Ca, Mg and S, Calcium deficiency severely affects the overall elemental composition. Fe, Zn, Cu, Mn and B contents recorded are 98.00, 22.00, 5.59, 59.35 and 11.71 ppm, respectively, under Ca deficiency as compared to the same of 208.32, 80.29, 11.32, 110.65 and 27.40 ppm in control with no deficiency (Singhal *et al.*, 1999a). Among micro nutrients (B, Cu, Fe, Mn and Zn), manganese deficiency causes sharp reduction in the quantity of all other elements. Next to Mn, Fe is also found as the critical element, deficiency of which causes a sharp reduction in K, Ca, S, Zn, Mn and B contents. Nitrogen among macro, Calcium among secondary and Manganese and Iron among micro nutrients are found as the critical elements affecting the overall elemental composition of the mulberry leaf. On feeding, such change in elemental composition adversely affects the silkworm rearing and in turn the silk yield.

Kumar and Sharma (1995) observed a significant decrease in leaf chlorophyll content and photosynthetic rate in mulberry under phosphorus deficiency. Mulberry leaf quality has been reported superior with balanced micro nutrients status of the soil (Bose *et al.*, 1995). The deficiency of secondary nutrients decreases growth and leaf yield of mulberry (Singh *et al.*, 1994). Besides, the mineral nutrition in relation to fundamental mechanisms, implications and applications in various agricultural crops has been reviewed in detail by Bergmann (1992), Marschner (1995), Gutierrez (1997) and Rengel (1999). Phosphorus deficiency affects the early development of wheat plants (Rodriguez *et al.*, 1994). Potassium deficiency in

Table 5. Change in elemental composition of mulberry leaf under nutrient deficiency

Nutrient deficiency	Macro elements (%)			Secondary elements (%)			Micro-nutrients (ppm)				
	N	P	K	Ca	Mg	S	Fe	Zn	Cu	Mn	B
Control	2.99	0.37	2.04	2.14	0.41	0.28	208.32	80.29	11.32	110.65	27.40
N	1.16	0.10	0.78	0.85	0.17	0.08	87.67	12.66	2.70	37.00	11.69
P	2.41	0.06	1.74	1.81	0.30	0.71	188.40	18.32	4.67	81.59	17.38
K	2.69	0.31	0.20	2.07	0.33	0.21	98.41	18.65	5.65	98.32	10.70
Ca	1.89	0.22	0.91	0.07	0.29	0.17	98.00	22.00	5.59	59.35	11.71
Mg	2.23	0.22	1.33	1.75	0.03	0.19	199.01	38.59	6.00	100.28	20.28
S	2.01	0.14	0.97	1.03	0.15	0.02	202.29	50.34	5.69	100.37	18.29
Fe	2.47	0.28	1.66	1.51	0.35	0.21	5.00	18.67	5.80	39.00	15.00
Zn	2.15	0.29	1.71	1.63	0.33	0.73	100.00	4.00	4.48	70.02	19.58
Cu	2.74	0.23	1.86	1.83	0.38	0.23	97.28	18.71	0.67	61.04	19.57
Mn	1.43	0.13	0.82	0.88	0.20	0.12	93.03	11.00	2.58	7.40	10.19
B	2.49	0.28	1.82	1.88	0.24	0.30	99.00	18.70	6.59	78.00	1.33
CD at 1%	0.30	0.06	0.38	0.15	0.06	0.04	15.16	4.37	2.42	11.65	4.51

Control = No deficiency for any element (Complete solution).

Table 6. Impact of mulberry leaf nutrient deficiency on silkworm (PM × NB_4D_2) economic characters

Nutrient deficiency in mulberry leaf	Percent reduction over control		
	Silkworm weight	Cocoon weight	Filament length
N	68.3	56.3	72.4
P	67.2	46.2	69.3
K	31.4	43.6	65.8
Ca	39.5	37.9	62.5
Mg	29.2	43.2	67.6
S	26.6	44.4	69.1
B	13.3	16.3	41.5
Cu	10.2	9.7	29.1
Fe	26.3	36.7	56.7
Mn	27.5	21.5	52.3
Zn	22.7	32.1	51.5

Shankar (1997).

potato causes blackening and detoriation of tubers quality (Zorn, 1995). Leaf K content is found closely correlated with soil K content. Pukhalskaya (1996) reviewed the effects of increasing atmospheric CO_2 concentration with reference to the combined effect of mineral nutrition on plant growth and the effects of increasing CO_2 concentration on uptake, accumulation and movement of mineral nutrients and on nitrogen fixation. The application of $NaHCO_3$ on mulberry is reported to influence the photosynthesis and silkworm cocoon yield and quality (Guo *et al.*, 2001). Shankar (1997) while working on effects of mulberry leaf nutrient deficiency for individual element on silkworm noted that the deficiency of Nitrogen among macro nutrients, Sulphur among secondary nutrients, and Mn & Zn among micro nutrients reduce silkworm filament length by more than 50% (Table 6). Bio-energetics of silkworm gets influenced when reared on fortificated mulberry leaves (Jayashankar *et al.*, 2001). The nutrition of phytophagus insects like silkworm is thus closely linked up with that of host plant which has also been discussed in detail by Singhal and Mala (1998) and Singhal *et al.* (2001b).

Leaf nutrient guide for mulberry

In recent past, many high yielding mulberry varieties have been evolved by the breeders grown in India and other sericultural countries. In most of the sericultural areas, mulberry gardens are either under-fertilized or over-fertilized (Gowda and Anjaneya, 1993). It is because of no systematic information is available in consolidated form on the critical level of nutrients required for the optimum leaf yield and quality of mulberry leaf. Under low or high doses of nutrients application than the critical level of their requirement leads to deficiency of one or the other nutrient or toxicity which adversely affects the mulberry leaf yield, its quality and thereby affects overall silk industry. Thus, for optimum leaf yield with desired quality, the critical level of the elements needs investigation. The critical level is the range of a given element in the leaf, below which the yield is limited and above which the use of fertilizer is either toxic or luxurient as well as not economical. In this regard, based on the extensive projects undertaken by us and the work carried out by others, data have been consolidated. Leaf nutrient guide for N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn in mulberry are summarized below.

Leaf nutrient guide for macro nutrients: 350 kg of nitrogen, 100 kg of phosphorus and 120 kg of potassium per hactare per year are the critical levels of their requirement for optimum growth and leaf yield in mulberry. Photosynthetic rate and other gas exchange traits are also efficient. Leaf quality is also optimum with protein content of about 23% under these critical levels which is considered as the desired protein content for successful cocoon crop. The leaf analysis status for elements namely N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn under these critical levels of N, P and K is also presented in Table 6. Any change in this status may adversely affect the mulberry leaf quality which needs correction (Table 7).

Leaf nutrient guide for secondary nutrients: Based on the morphological and physiological parameters as well as leaf tissue analysis for leaf quality and elemental composition, 0.25% Calcium, 0.15% Magnesium and 0.32% Sulphur are the critical levels of their requirement for optimum growth and leaf quality of mulberry (Table 8).

Leaf nutrient guide for micro-nutrients: The critical levels for B, Cu, Fe, Mn and Zn are 0.45, 0.55, 0.11, 0.16 and 0.24 kg/ha/crop, respectively based on growth and yield parameters, physiological traits, leaf quality and elemental status. Any change in leaf nutrient status needs soil correction to obtain desired leaf quality (Table 9).

The optimum level of nutrients requirement for other agricultural crops has also been reported. Lallu *et al.* (1997) found optimum level of sulphur as 0.45 to 0.48% for maximum seed production in Rai (*Brassica juncea*). The nutrient guide for sulphur has been highlighted by Kaleeswan and Kumaraswamy (1998) in the crops like rice, wheat, maize, jowar, soyabean, tomato, potato, turnips, cucumber, lettuce, groundnut, palms, sugarcane, cotton, tobacco, coffee and tea. Different minerals have extensively been used in various agricultural crops for checking nutrients deficiency and thereby for increasing crop productivity (Zende, 1998). Nutritional disorders and nutrient guide is available for various agricultural crops

Table 7. Plant growth, leaf yield, gas exchange traits, leaf quality and elemental composition under critical levels of macro-nutrients (Nitrogen, Phosphorus and Potassium) requirement in mulberry

Parameters	Critical levels of macro-nutrients requirement (kg/ha/yr)		
	Nitrogen	Phosphorus	Potassium
	350	100	120
Plant growth and yield parameters:			
Plant height (cm)	55.19	54.72	55.91
Number of leaves/plant	15.06	16.70	15.54
Total leaf area/plant (cm^2)	1214.94	1205.72	1222.59
Leaf yield per plant (g)	30.49	27.78	27.23
Leaf dry matter/plant (g)	9.19	8.43	8.29
Gas exchange traits:			
Photosynthetic rate (μ mole m^{-2} s^{-1})	15.24	13.55	13.46
Stomatal conductance (μ mole m^{-2} s^{-1})	0.426	0.522	0.526
Intercellular CO_2 conc. (ppm)	353.03	286.71	287.87
Transpiration rate (μ mole m^{-2} s^{-1})	0.0030	0.0032	0.0032
Leaf quality:			
Chlorophyll 'a' (mg/g)	2.227	2.233	2.215
Chlorophyll 'b' (mg/g)	0.787	0.647	0.710
Protein%	23.17	22.91	23.39
Ascorbic acid %	0.226	0.223	0.223
Carotenoids (mg/g)	0.823	0.823	0.821
Elemental composition:			
Nitrogen %	3.88	3.87	3.88
Phosphorus%	0.43	0.43	0.41
Potassium %	2.07	2.33	2.11
Calcium %	2.19	2.24	2.26
Magnesium %	0.48	0.41	0.47
Sulphur %	0.32	0.32	0.36
Iron (ppm)	222.02	228.81	227.00
Zinc (ppm)	87.09	82.91	88.21
Copper (ppm)	12.75	12.96	13.67
Manganese (ppm)	119.88	112.89	123.62
Boron (ppm)	29.88	26.71	30.79

Table 8. Plant growth, leaf yield, gas exchange traits, leaf quality and elemental composition under critical levels of secondary nutrients (Calcium, Magnesium and Sulphur requirement in mulberr

Parameters	Critical levels of secondary nutrients requirement (%)		
	Calcium	Magnesium	Sulphur
	0.25	0.15	0.32
Plant growth and yield parameters:			
Plant height (cm)	49.04	55.52	64.63
Number of leaves/plant	14.34	15.98	20.38
Total leaf area/plant (cm^2)	984.05	1085.02	1381.31
Leaf yield per plant (g)	28.72	32.08	27.63
Leaf dry matter/plant (g)	8.34	9.27	8.08
Gas exchange traits:			
Photosynthetic rate (μ mole m^{-2} s^{-1})	9.22	13.19	11.54
Stomatal conductance (μ mole m^{-2} s^{-1})	0.346	0.526	0.421
Intercellular CO_2 conc. (ppm)	253.33	287.08	278.82
Transpiration rate (μ mole m^{-2} s^{-1})	0.0027	0.0036	0.0040
Leaf quality:			
Chlorophyll 'a' (mg/g)	1.500	1.826	2.181
Chlorophyll 'b' (mg/g)		0.530	0.663
Protein %	19.75	21.24	22.41
Ascorbic acid %	0.224	0.223	0.224
Carotenoids (mg/g)	0.820	0.825	0.822
Elemental composition:			
Nitrogen %	3.80	3.79	3.84
Phosphorus %	0.39	0.37	0.42
Potassium %	2.03	2.04	2.03
Calcium %	2.02	2.12	2.15
Magnesium %	0.48	0.40	0.47
Sulphur %	0.32	0.34	0.36
Iron (ppm)	220.81	216.17	221.47
Zinc (ppm)	90.15	83.98	90.45
Copper (ppm)	12.90	12.62	11.69
Manganese (ppm)	107.46	112.52	109.58
Boron (ppm)	32.07	37.19	33.86

like ginger (Asher and Lee, 1975), cassava (Asher *et al.,* 1980), fruit trees (Atkinson *et al.,* 1980), chilli (Balakrishnan, 1999), fruit and plantation crops (Bhargava and Chadha, 1988), ber (Bhargava *et al.*, 1990; Raturi and Bhargava, 1993), sunflower (Blamey *et al.,* 1987), citrus (Bojappa and Bhargava, 1993), grain sorghum (Grundon *et al.,* 1987), strawberry (Johanson, 1980), vegetable crops (Maynard, 1979) and various other crops (Rengel, 1999).

Table 9. Plant growth, leaf yield, gas exchange traits, leaf quality and elemental composition under critical levels of micro-nutrients (boron, copper, iron, manganese and zinc) requirement in mulberry

Parameters	Critical levels of micro-nutrients requirement (Kg/ha/crop)				
	Boron	Copper	Iron	Manganese	Zinc
	0.45	0.55	0.11	0.16	0.24
Plant growth and yield parameters:					
Plant height (cm)	60.29	55.19	60.13	60.12	57.60
Number of leaves/plant	16.25	19.02	21.01	20.19	16.58
Total leaf area/plant (cm^2)	1407.58	1362.52	1462.15	1439.47	1297.79
Leaf yield per plant (g)	27.958	28.05	28.13	30.13	25.85
Leaf dry matter/plant (g)	9.31	8.17	8.88	9.08	7.75
Gas exchange traits:					
Photosynthetic rate (μ mole m^{-2} s^{-1})	13.04	13.21	12.91	12.99	13.83
Stomatal conductance (μ mole m^{-2} s^{-1})	0.475	0.461	0.489	0.477	0.448
Intercellular CO_2 conc. (ppm)	291.14	301.17	266.36	263.74	309.83
Transpiration rate (μ mole m^{-2} s^{-1})	0.0038	0.0040	0.0036	0.0037	0.0039
Leaf quality:					
Chlorophyll 'a' (mg/g)	2.116	2.304	2.079	2.078	2.377
Chlorophyll 'b' (mg/g)	0.710	0.719	0.688	0.688	0.734
Protein %	20.06	20.06	20.01	19.92	20.23
Ascorbic acid %	0.227	0.225	0.225	0.227	0.221
Carotenoids (mg/g)	0.829	0.829	0.826	0.828	0.829
Elemental composition:					
Nitrogen %	3.78	3.78	3.77	3.76	3.75
Phosphorus %	0.32	0.37	0.38	0.39	0.36
Potassium %	2.11	2.00	2.06	2.03	2.00
Calcium %	2.14	2.05	2.11	2.11	2.12
Magnesium %	0.43	0.40	0.41	0.42	0.42
Sulphur%	0.39	0.35	0.36	0.38	0.38
Iron (ppm)	222.17	215.08	220.16	218.17	215.71
Zinc (ppm)	88.28	88.33	85.16	87.17	93.18
Copper (ppm)	16.55	17.98	17.93	17.95	16.91
Manganese (ppm)	115.91	112.56	111.77	111.92	108.55
Boron (ppm)	41.07	40.39	39.42	39.52	37.55

Need for integrated nutrient management

Though a significant improvement in quantity and quality of mulberry leaf could be achieved by the adoption of information detailed in this paper, still, the yield and quality remain low due to poor economic condition of the farmers and no application of required fertilizers to their cultivated fields. In this regard, an integrated approach for nutrients management is suggested as mentioned below.

Development of suitable water management system: Insitu soil moisture conservation plays an important role in increasing the yield of mulberry in soil moisture stress areas totally dependent on rainfall. Aqueel *et al.* (2000) found dead furrow with vertical mulch system as the best method for significantly higher soil moisture and leaf yield. Mishra *et al.* (2002) advocated drip irrigation system during non-rainy period and explored the possibilities of saving about 40% water.

VA-mycorrhizal (VAM) inoculation: Katiyar *et al.* (1995, 2000) and Fathima *et al.* (2002) suggested that established mulberry garden can effectively be inoculated with VAM by growing maize as carrier host for saving phosphatic fertilizer to economize mulberry cultivation. Inoculation is done once by sowing maize seeds along with mixed culture of *Glomus mosseae* and *G. fascicu-*

latum at 1000 kg soil based inoculum (218 spores per 10 g of soil) per hectare in the furrows between mulberry rows. 90 kg of chemical phosphorus/ha/yr can be curtailed by this method without loss in leaf yield and quality.

Azotobactor biofertilizer utilization: The higher requirement of chemical fertilizers especially nitrogen (300 – 350 kg N/ha/yr) increase the cost of mulberry cultivation. These fertilizers are expensive and beyond reach to small and marginal farmers. Moreover, continuous use of chemical fertilizers deteriorates soil condition. Azotobactor biofertilizer is thus recommended in mulberry cultivation to make sericulture industry more profitable. Dandin *et al.* (2000) advocated to apply 20 kg Azotobactor biofertilizer/ ha/yr in 5 split doses at the rate of 4 kg each time after every pruning and intercultural operations. It cuts down cost by 50% in the total application of nitrogen fertilizer.
Vermicompost utilization: A technique for composting of waste within 50 – 60 days using earthworms as versatile bioreactor is developed for nutrient management. A mixed culture of earthworms (*Eudrilus eugeniae*, *Eisenia foetida*, *Perionyx excavatus* in juvenile stage can be introduced in the feed at the rate of 1.5 kg per metric tonne of wastes in each trench and left for earthworms activity for 6 – 7 weeks as per the guidelines provided by Dandin *et al.* (2000) for preparation of vermi-composting. The chemical analysis of prepared vermicompost *vis-a-vis* farmyard manure (FYM) and effect of vermicompost *vis-a-vis* FYM on quality of mulberry leaf are provided in Tables 10 and 11. As revealed from the tables, vermicompost is rich in nutrients as compared to FYM and its application at the rate of 5.6 MT/ha/yr provides same leaf quality as is being obtained by FYM application at the rate of 20 MT/ha/yr. Such technology can help in integrated nutrient management by the farmer's to improve their economy.

Composting of sericulture waste: There is lot of sericulture waste including mulberry leaf and silkworm litter which can be converted into the valuable manure by using composting technology (Singhal *et al.*, 2001a). The detailed technology has been described by Dandin *et al.* (2000).

Table 10. Nutrient status of vermicompost and farmyard manure

Nutrient	Vermicompost	Farmyard manure
N	1.87 – 2.00%	0.3 – 0.5%
P	0.60 – 0.90%	0.2 – 0.4%
K	1.00 – 1.50%	0.3 – 0.6%
Cu	61.50 ppm	2.8 ppm
Fe	1247.00 ppm	Not available
Mn	509.70 ppm	69.0 ppm
Zn	84.60 ppm	14.5 ppm

Dandin *et al.* (2000).

Table 11. Effect of vermicompost and farmyard manure on quality of mulberry leaf

Type of compost applied	Major elements status (%)		
	N	P	K
Vermicompost at the rate of 5.6 MT/ha/yr	3.83	0.29	2.10
FYM at the rate of 20 MT/ha/yr	3.67	0.29	2.02

Chemical fertilizers at the rate of 300:120:120 kg N:P:K/ha/yr

Dandin *et al.* (2000).

Table 12. Nutrients status of FYM, neem cake and castor oil cake

Manure	Nutrient level (%)		
	N	P	K
FYM	0.5	0.3	0.5
Neem oil cake	5.2	1.0	1.4
Castor oil cake	4.3	1.8	1.3

Shankar (1997).

Use of green manures: Shankar (1997) reported that sowing of green manure seed at 30 kg/ha in between harvests of two crops of mulberry is not only beneficial in increasing the mulberry yield but also results in improvement in soil status. However, the benefit of green manures can be noted only after their continuous application at least for 2 to 3 crops under irrigated conditions. Improvement in mulberry leaf yield and quality as well as soil status is possible by growing cowpea, groundnut, cluster bean, soya bean as intercrop in mulberry under dry land condition. Neem and castor oil cakes can also be used in mulberry cultivation because of their high nutrients status as compared to FYM (Table 12) besides controlling mulberry diseases and nematodes infestation. This system enhances the fertilizer use efficiency and better use of organic and natural resources. Chowdary *et al.* (2003) emphasized for incorporation of green manure in the soil for balanced nutrient management.

In a situation where there is demand for higher production of quality leaves of mulberry especially in India, there is an urgent need for judicious use of required chemical fertilizers with integration of inorganic nutrient components in package of practices with eco-friendly, cheaper and locally prepared organic manure in the form of VA-mycorrhizal inoculation, biofertilizer, vermicompost, green manure, etc. Thus, the future scenario should be for correct identification of nutrient deficiency, proper analytical diagnosis of leaf and application of each element to its critical need with application of integrated nutrient management for sustainable sericulture industry.

References

Aqueel, S. A., R. K. Mishra, Dayananda, H. Jayaram, S. Ravindran, L. Rajanna and Y. R. Madhavarao (2000) *In situ* soil moisture conservation technology for mulberry cultivaton under rainfed conditions. Seminar on Sericulture Technology: An Appraisal. June 6-7, Central Sericultural Research and Training Institute, Mysore, p. 39.

Asher, C. J., D. G. Edwards and R. H. Howeler (1980) Nutritional disorders of cassava. University of Queensland, St. Lucia.

Asher, C. J. and M. T. Lee (1975) Nutritional disorders in ginger. University of Queensland, St. Lucia.

Atkinson, D., J. E. Jackson, R. O. Sharples and W. M. Waller (1980) Mineral nutrition of fruit trees. Butterworths, London.

Balakrishnan, K. (1999) Studies on nutrients deficiency symptoms in chilli (*Capsicum annum* L.). *Indian J. Plant Physiol.* **4**, 229-231.

Bergmann, W. (1992) Nutritional disorders of plants - Development, visual and analytical diagnosis, Gustav Fischer, New York.

Bhargava, B. S., G. B. Raturi and S. S. Hiwale (1990) Leaf sampling in ber (*Zizyphus mauritiana* Lam) for nutritional diagnosis. *Singapore J. Pri. Ind.* **18**, 85-95.

Bhargava, B. S. and K. L. Chadha (1988) Leaf nutrient guide for fruit and plantation crops. *Fertilizer News* **33**, 21-29.

Blamey, F. P. C., D. G. Edwards and C. J. Asher (1987) Nutritional disorders of sunflower, University of Queensland, Australia.

Bojappa, K. M. and B. S. Bhargava (1993) Citrus nutrition; in *Advances in Horticulture, Vol. 2 - Field crops.* Chadha, K. L. and O. P. Pareek (eds.), pp. 829-852, Malhotra Publishing House, New Delhi, India.

Bongale, U. D. (1995) Chlorosis in mulberry and remedial measures. *Indian Silk* **34**, 34-37.

Bongale, U. D. (1997) Potassium deficiency symptoms in certain important varieties of mulberry (*Morus* sp.) under field plantation in Karnataka (India). *Indian J. Seric.* **36**, 78-80.

Bongale, U. D. and Lingaiah (1998) Macro and micronutrient status of mulberry garden soils in a bivoltine seed area. *Indian J. Seric.* **37**, 73-75.

Bongale, U. D., M. Krishna and Chaluvachari (1996) Effect of multinutrient foliar spray on chlorosis in M-5 variety of mulberry. *Indian J. Seric.* **35**, 9-12.

Bose, P. C., N. R. Singhvi and R. K. Datta (1995) Effect of micronutrients on the biochemical parameters of mulberry (*Morus alba* L.) leaf. *Sericologia* **35**, 65-69.

Brown, J. C. (1979) Genetic improvement and nutrient uptake in plants. *Bio. Sci.* **25**, 289-292.

Chakraborti, S. and B. K. Singhal (1996) Seasonal variation in ascorbic acid content of promising mulberry genotypes. *Indian J. Plant Physiol.* **1**, 298-299.

Chakraborti, S., M. R. Subramanyam, B. K. Singhal and R. K. Datta (1997) Nutrient deficiency management in mulberry - A key for identification of hunger signs. Central Sericultural Research and Training Institute, Mysore, India.

Chakraborty, M. K. and A. K. Medda (1978) Effect of potassium iodide on silkworms (*Bombyx mori* L.) Nistari race. *Sci. Cult.* **44**, 231-233.

Chamundeswari, P. and K. Radhakrishnaiah (1994) Effect of zinc and nickel on the larval and cocoon characters of the silkworm, *Bombyx mori* L. *Sericologia* **34**, 327-330.

Chikkaswamy, B. K., M. Shivashankar and H. P. Puttaraju (2000) Effect of foliar spray of micro-nutrients on different mulberry varieties in relation to silkworm cocoon characters; in *Moriculture in tropics.* Chinnaswamy, K. P., R. Govindan, N. K. Krishnaprasad and D. N. R. Reddy (eds.), pp.132-134, Department of Sericulture, University of Agricultural Sciences, Bangalore and Seri 2000, Swiss Agency for Development and Co-operation, Bangalore, India.

Chowdary, N. B., Govindaiah and D. D. Sharma (2003) Impact of balanced fertilizers on mulberry leaf yield. *Indian Silk* **42**, 5-7.

Christiansen, M. N. and C. D. Foy (1979) Fate and function of calcium in tissue. *Comm. Soil Sci. Plant Analysis* **10**, 427-442.

Dadmal, S. M., S. K. Aherkar, M. Sajid and D. N. Sarnaik (2001) Preliminary studies on the effect of ascorbic acid enriched mulberry leaves on *Bombyx mori* L. *Insect Environ.* **7**, 40.

Dandin, S. B., H. K. Basavaraja and N. Sureshkumar (2003) Factors for success of Indian bivoltine sericulture. *Indian Silk* **41**, 5-8.

Dandin, S. B., J. Jayaswal and K. Giridhar (2000) Handbook of sericulture technologies. Central Silk Board, Bangalore, India.

Dasmahapatra, A. K., M. K. Chakrabarti and A. K. Medda (1989) Effect of potassium iodide, cobalt chloride, calcium chloride and potassium nitrate on protein, RNA and DNA contents of silkgland of silkworm (*Bombyx mori* L.), Nistari race. *Sericologia* **29**, 355-359.

Datta Gupta, S., C. Roychaudhuri and I. D. Chatterjee (1972) Incapability of L-ascorbic acid synthesis by insects. *Arch. Biochem. Biophy.* **152**, 889-890.

Epstein, E. (1972) Mineral nutrition of plants: Principles and perspectives. John Wiley & Sons Inc., New York - London - Sydney -Toronto.

Fathima, P. S., P. K. Das and R. S. Katiyar (2000) Effect of different levels and sources of phosphorus on VA-mycorrhizal root colonization and spore load in mulberry (*Morus alba* L.). *Crop Res.* **20**, 504-508.

Gowda, D. W. (1993) A study on adoption behaviour of big, small and marginal sericulturists and their characteristics in Kolar district. Masters Thesis, Central Sericultural Research and Training Institute, Mysore.

Gowda, Raje (2002) Impact of Seripro on cocoon production and productivity in silkworm, *Bombyx mori* L.; in *Advances in Indian sericulture research.* Dandin, S. B. and V. P. Gupta (eds.), pp. 264-266, Central Sericultural Research and Training Institute, Mysore, India.

Grundon, N. J., D. G. Edwards, P. N. Takkar, C. J. Asher and R. B. Clark (1987) Nutritional disorders of grain sorghum. ACIAR Monograph No. 2, Australian centre for International agricultural research, Canberra, Australia.

Guo, J. H., Z. D. Niu, J. S. Mel, X. Q. Xia, M. Hu and Y. Z. Wang (2001) Effect of $NaHSO_3$ on mulberry (*Morus alba*) photosynthesis and silkworm (*Bombyx mori*) cocoon yield and quality. *Sericologica* **27**, 83-86.

Gutierrez, M. V. (1997) Mineral nutrition of plants: advances and applications. *Agronomia - Costarricense* **21**, 127-137.

Horie, Y., K. Watanabe and T. Ito (1967) Nutrition of the silkworm, *Bombyx mori.* XVIII. Quantitative requirements for potassium, phosphorus, magnesium and zinc. *Bull. Sericult. Exp. Sta.* **22**, 181-193.

Horie, Y. and M. Watanabe (1980) Recent advances in sericulture. *Ann. Rev. Entomol.* **25**, 49-71.

Horst, M. (1995) Mineral nutrition of higher plants. Academic Press, London.

Ito, T. (1961) Effect of dietary ascorbic acid on the silkworm, *Bombyx mori* L. *Nature* **192**, 951-952.

Ito, T. and M. Nimura (1966) Nutrition of the silkworm, *Bombyx mori.* XII. Nutritive effect of minerals. *Bull. Sericult. Exp. Sta.* **20**, 363-374.

Ito, T. and N. Arai (1965) Nutrition of the silkworm *Bombyx mori* IX. Further studies on the nutritive effects of ascorbic acid. *Bull. Sericult. Exp. Sta.* **20**, 1-19.

Jayaprakashrao, M., K. S. Badiger and G. M. Patil (1998) Boosting silk yield. *Indian Textile J.* **108**, 58-59.

Jayashankar, A., N. Raja, K. Elumalal, M. Jayakumar, A. Thangamani and S. Ignachimuthu (2001) Bio-energetics of silkworm, *Bombyx mori* L. reared on fortificated mulberry leaves. *J. Interacademicia* **5**, 340-345.

Johanson, F. R. (1980) Hunger in strawberries. K & H Printers Inc., Washington, USA.

Kaleeswan, R. K. and K. Kumaraswamy (1998) Crop responses to sulphur application. *Micronutrient News* **12**, 2-3.

Kanwar, J. S. (1978) Soil fertility: Theory and Practice. Indian Council of Agricultural Research, New Delhi, India.

Katiyar, R. S., P. K. Das, P. C. Choudhury, A. Ghosh, G. B. Singh and R. K. Datta (1995) Response of irrigated mulberry (*Morus alba* L.) to VA-mycorrhizal inoculation under graded doses of phosphorus. *Plant Soil* **170**, 331-337.

Katiyar, R. S., P. K. Das, Y. R. Madhavarao, K. M. Vijayakumari and M. T. Himanthraj (2000) Response of established mulberry garden to VA-mycorrhizal inoculation. Seminar on Sericulture Technology: An Appraisal. June 6-7, Central Sericultural Research and Training Institute, Mysore, India.

Kumar, N. and P. N. Sharma (1995) Effect of phosphorus deficiency stress on photosynthesis in mulberry (*Morus alba* L.). *Indian J. Expt. Biol.* **33**, 616-619.

Lallu, H., K. Sexena and H. Shankar (1997) Critical sulphur requirement in plants and in nutrients medium for yield of Indian mustard (*Brassica juncea* L.) Czern & Coss, *Indian J. Plant Physiol.* **2**, 54-58.

Loknath, R. and K. Shivashankar (1985) Effect of foliar application of magnesium and micronutrients to mulberry on the quality and production of cocoons. *Indian J. Seric.* **21**, 40-41.

Lundegardh, H. (1943) Leaf analysis as a guide to soil fertilizer. *Nature* **151**, 310.

Machii, H. and K. Katagiri (1991) Varietal differences in nutritive values of mulberry leaves for rearing silkworms. *JARQ* **25**, 202-208.

Magadum, S. B., M. A. Hooli and V. B. Magadum (1992) Effect of feeding copper sulphate on the economic parameters of the polyvoltine silkworm, *Bombyx mori* L. *Sericologia* **32**, 395-399.

Majumdar, A. C. (1982) Note on the physiological effects on the growth and reproduction of silkworm fed on mulberry leaves soaked in potassium iodide. *Indian J. Agric. Sci.* **52**, 250-252.

Manimegalai, S., A. Subramanian and N. Chandramohan (2002) Enhancement of cocoon yield in silkworm, *Bombyx mori* L. by protein supplementation in shoot rearing. *Madras Agric. J.* **89**, 400-402.

Marschner, H. (1995) Mineral nutrition of higher plants. Institute of Plant Nutrition, Stuttgart, Germany.

Maynard, D. N. (1979) Nutritional disorders of vegetable crops: a review. *J. Plant Nutrition* **1**, 1-23.

Maynard, I. A., I. K. Loosli, H. P. Hintz and R. G. Warner (1984) The inorganic elements and their metabolism; in *Animal nutrition.* pp. 202-210. Tata McGraw Hill Publishing Co., India.

Mengel, K. and E. A. Krikby (1978) Principles of plant nutrition. International Potash Institute, Switzerland.

Menon, K. K. G. and H. C. Srivastava (1984) Increasing plant productivity through improved photosynthesis. *Proc. Indian Acad. Sci.* **93**, 339-378.

Millaway, R. M. and L. Wiersholm (1979) Calcium and metabolic disorders. *Comm. Soil Sci. Plant Analysis* **10**, 1-28.

Mishra, R. K., S. Ravindran, Y. R. Madhvarao and L. Rajanna (2002) Efficacy of drip irrigation in mulberry during non-rainy period; in *Advances in Indian sericulture research.* Dandin, S. B. and V. P. Gupta (eds.), pp. 224-227, Central Sericultural Research and Training Institute, Mysore, India.

Miyashita, V. (1986) A report on mulberry cultivation and training methods suitable to bivoltine rearing in Karnataka, Central Silk Board, Bangalore, India.

Miyoshi, T., F. Miyazawa and O. C. Shimizu (1978) Effect of heavy metals on mulberry plant and silkworm. IV. The relation between different compounds of heavy metals by the silkworm, *Bombyx mori* L. *J. Seric. Sci. Jpn* **47**, 101-107.

Murali, K., S. Thimme Gowda and Malleshaiah (2000) Effect of method of pruning and sulphur source on cocoon characters and silk quality; in *Moriculture in tropics.* Chinnaswamy, K. P., R. Govindan, N. K. Krishnaprasad and D. N. R. Reddy (eds.), pp. 103-105, Department of Sericulture, University of Agricultural Sciences, Bangalore and Seri 2000, Swiss Agency for Development and Co-operation, Bangalore, India.

Pukhalskaya, N. V. (1996) Mineral nutrition of plants in connection with global increase of atmospheric CO_2 concentration. *Sel'skokhozya - istvennaya - Biologiya* **1**, 27-40.

Radha, N. V., P. Nagarajan and S. Jayaraj (1988) Mineral deficiency in mulberry plants, *Morus* sp. and its effect on economic characters of silkworm, *Bombyx mori* L. *Madras Agric. J.* **73**, 384-390.

Rai, M. M., M. K. Rathod and A. M. Khurad (2002) Improvement in economic characters of silkworm, *Bombyx mori* L. by folic acid administration. *Entomon* **27**, 99-104.

Raturi, G. B. and B. S. Bhargava (1993) Leaf sampling guide for nutrient management in ber. *Indian J. Horticult.* **50**, 202-208.

Rengel, Z. (1999) Mineral nutrition of crops: fundamental mechanisms and implications. University of W. Australia, Perth, Australia.

Rodriguez, D., G. E. Santa-maria and M. C. Pomar (1994) Phosphorus deficiency affects the early development of wheat plants. *J. Agronomy Crop Sci.* **173**, 69-72.

Sannappa, B., M. C. Devaiah and R. Govindan (2002) Influence of methods and frequencies of feeding rainfed mulberry raised with varied nitrogen levels on rearing performance of *Bombyx mori*; in *Advances in Indian sericulture research.* Dandin, S. B. and V. P. Gupta (eds.), pp. 291-295, Central Sericultural Research and Training Institute, Mysore, India.

Shankar, A. A. and A. A. Absar (1995) Foliar treatment of urea and micro nutrients on mulberry and silkworm. *Sericologia* **35**, 713-720.

Shankar, M. A. (1997) Handbook of mulberry nutrition. Department of Sericulture, UAS, Bangalore and Multiplex, Bangalore, India.

Shankar, M. A. and K. Shivashankar (1994) Growth, development and leaf yield in S-54 mulberry as influenced by deficiency of secondary nutrients. *Sericologia* **34**, 353-358.

Shankar, M. A., K. Shivashankar and M. C. Devaiah (1994) Effect of feeding mulberry leaves deficient in secondary nutrients on larval growth, development, cocoon weight and silk quality. *Sericologia* **34**, 511-518.

Shylaja, B. M. (1996) Influence of different levels of nitrogen on physiological and biochemical parameters on leaf quality in some promising mulberry (*Morus* spp.) varieties. Masters Thesis, University of Mysore, Mysore, India.

Singh, K. P. (1997) Micronutrients in mulberry (*Morus alba* L.) cultivation - an overview. *Sericologia* **37**, 603-617.

Singh, K. P., R. S. Teotia and S. K. Sen (1994) Role of secondary macronutrients in mulberry cultivation. *Sericologia* **34**, 401-413.

Singh, M. V. (1999) Micronutrient deficiencies in Indian soils. *Micronutrient news* **13**, 1-3.

Singhal, B. K., A. Dhar, Aradhana Sharma, S. M. H. Qadri and M. M. Ahsan (2001a) Sericultural by-products for various valuable commercial products as emerging bio science industry. *Sericologia* **41**, 369-391.

Singhal, B. K., A. Dhar, S. M. H. Qadri and M. M. Ahsan (2001b) Mulberry nutrition for development of sericulture in Jammu and Kashmir. *Asian Textile J.* **10**, 35-42.

Singhal, B. K., S. Chakraborti, V. R. Mala, A. Sarkar and R. K. Datta (2000a) Photosynthesis for crop improvement in mulberry (*Morus* spp.) - a review. *Sericologia* **40**, 27-55.

Singhal, B. K. and V. R. Mala (1998) An insight into silkworm's food. *Indian Textile J.* **108**, 86-88.

Singhal, B. K., V. R. Mala, A. Sarkar and R. K. Datta (1999a) Nutritional disorders of mulberry (*Morus* spp.) III. Leaf nutrient guide for secondary nutrients. *Sericologia* **39**, 599-609.

Singhal, B. K., V. R. Mala, A. Sarkar and R. K. Datta (2000b) Nutritional disorders of mulberry. II. Leaf nutrient guide for N, P and K under tropical condition; in *Moriculture in tropics.* Chinnaswamy, K. P., R. Govindan, N. K. Krishnaprasad and D. N. R. Reddy (eds.), pp.109-113, Department of Sericulture, University of Agricultural Sciences, Bangalore and Seri 2000, Swiss Agency for Development and Co-operation, Bangalore, India.

Singhal, B. K., V. R. Mala and S. Chakraborti (1999b) Nutritional disorders of mulberry (*Morus* spp.) I. Effect of deficiencies on physiological and biochemical processes. *Philippine J. Sci.* **128**, 161-170.

Singhal, B. K., V. R. Mala and V. Kumar (1998) Indian Sericulture - Problems and prospects. *Modern Textile J.* **4**, 27-35.

Singhvi, N. R., J. Kodandaramaiah, M. Munirathnam Reddy, R. S. Katiyar and A. Sarkar (2002a) Symptomatological study of nutrient deficiency in mulberry variety V-1 under field conditions. *Indian J. Seric.* **41**, 66-69.

Singhvi, N. R., J. Kodandaramaiah, M. Munirathnam Reddy, R. S. Katiyar, A. Sarkar and R. K. Datta (2002b) Study on nutrient deficiency in mulberry variety S-36 under field conditions. *Sericologia* **42**, 53-58.

Subbaswamy, M. R., B. Srinath, B. V. Naidu, A. Venugopal, N. Suryanarayana, N. R. Singhvi and R. K. Datta (2000) Soil fertility - a major reason for yield gap in sericulture. *Indian Silk* **39**, 5-6.

Subbaswamy, M. R., N. R. Singhvi, S. B. Magadum, K. Vedavyasan, E. B. Srinivasan, M. M. Reddy, A. Sarkar and R. K. Datta (2001) Mulberry nutrition and flacherie occurrence at field level. *Indian Silk* **40**, 13-14.

Subburathinam, K. M. and J. Sulochanachetty (1991) Effect of fortification of mulberry leaves with minerals to silkworm, *Bombyx mori* L. *Indian J. Seric.* **30**, 121-123.

Subburathinam, K. M., M. Krishnan and J. Sulochanachetty (1993) Effect of minerals on the bioenergetics of the silkworm *Bombyx mori*. *Sericologia* **33**, 121-123.

Subburathinam, K. M., V. Kabila and J. Sulochanachetty (1990) Mineral spray can increase cocoon quality. *Indian Silk* **28**, 35-36.

Sunder Raj, S., Neelu Nangia and K. P. Chinnaswamy (2002) Correlation co-efficients of economic traits of silkworm, *Bombyx mori* (Lepidoptera:Bombycidae) reared on the leaves enriched with protein supplements; in *Advances in Indian sericulture research.* Dandin, S. B. and V. P. Gupta (eds.), pp. 332-335, Central Sericultural Research and Training Institute, Mysore, India.

Takagishi, H., K. Shirata, I. Kawanchi, K. Watanabe and Y. Horie (1985) Effect of fortification on leaf yield and quality of mulberry. *Bull. Sericult. Exp. Sta. Jpn* **30**, 65-79.

Tandon, H. L. S. (2002) Dictionary of secondary and micronutrients. Fertilizer Development and Consultation Organization, New Delhi, India.

Thangavelu, K. and H. R. Bania (1990) Preliminary investigation on the effects of minerals in the rain water on the growth and reproduction of silkworm, *Bombyx mori* L. *Indian J. Seric.* **29**, 37-43.

Tsuneyama, I. and Y. Tanaka (2001) Effect of $CaCO_3$ on the feeding behaviour of the newly hatched larvae of the silkworm, *Bombyx mori. J. Seric. Sci. Jpn* **70**, 97-101.

Viswanath, A. P. (1979) Effect of foliar spray of micronutrients on the yield and quality of mulberry (*Morus alba* L.). Masters Thesis, University of Agricultural Sciences, Bangalore, India.

Viswanath, A. P. and K. Krishnamoorthy (1982) Effect of foliar spray of micronutrients on the larval development and cocoon characters of silkworm, *Bombyx mori* L. *Indian J. Seric.* **22**, 1-6.

Zende, G. K. (1998) Utility of micronutrients in increasing sugarcane and sugar productivity in maharashtra. *Micronutrient News* **12**, 1-3.

Zorn, W. (1995) Potassium deficiency in potatoes. *Kartoffelbau* **46**, 50-51.