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Optimum Nutrient Rate and Nutritional Constraints in Tuber Crops Growing in Ultisol of India with Special Emphasis on Tannia

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*Tuber crops are generally grown in marginal lands with low native soil fertility. In India, laterite soils (acidic Ultisols) are the major soils for tropical tuber crops and are poor in innate fertility. Among tropical tuber crops, some have adapted to poor soils, such as cassava, whereas others such as tannia (*Xanthosoma sagittifolium *L.) cannot establish well in these soils and may manifest nutritional disorders, which ultimately result in the complete devastation of the crop. Therefore, we investigated the effects from a preliminary rate trial (PRT) and nutrient-omission pot trial (NOPT) using maize as a test crop and a NOPT with tannia to determine the optimum nutrient rate and limiting nutrients, as well as nutritional problems affecting the growth and yield of tannia. Each experiment was laid out in a complete randomized design with three replications and was conducted for both garden and paddy soils. The PRT revealed that the optimum nutrient requirements for the soils were different, with garden soils requiring nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), zinc (Zn), and molybdenum (Mo) at 200, 60, 160, 70, 60, 50, 4, 8, and 0.8 kg ha^{-1}, respectively, and paddy soil requiring twice these rates. The NOPT indicated that in addition to N, P, K, B, and Mo in both garden and paddy soils, Ca and Zn in paddy soils and S in garden soils were the constraining nutrients. The NOPT carried out with tannia indicated that the main nutritional problem was subsoil acidity-induced multinutrient deficiencies involving K, Ca, and Mg.*

Keywords Acidity, constraint nutrients, laterite soil, nutrient-omission pot trial, nutritional disorders, optimum nutrient rate, preliminary rate trial, tannia

Introduction

Tropical tuber crops play a significant role in the food and nutritional security of more than 500 million of the world's population, who depend upon their starchy root for food, feed, and income. In the majority of the countries that grow tuber crops, these crops are grown in neglected lands of poor to marginal fertility. Though these crops are adapted to soils of poor native fertility, it is proven that application of greater levels of fertilizers and manures can maximize yield, which indicates a positive response to manures and fertilizers.

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Cassava, sweet potato, and yams grow well in soils of poor innate fertility without exhibiting typical symptoms of nutrient disorders. However, aroids, especially taro and tannia, respond differently to various nutrients in the soil. Research carried out with these crops indicated that there were soil nutritional constraints affecting the growth and yield of these crops. In these crops, especially tannia (*Xanthosoma sagittifolium*), until the third month of the crop cycle, growth was sufficient if there was medium soil fertility, adequate soil moisture, and moderate humidity. Later, slight interveinal chlorosis in the older leaves appeared and was found to spread very rapidly, followed by inward cupping, necrosis, and drying of the entire leaves, resulting in the death of the plant. These symptoms were typical of magnesium (Mg) deficiency. In severe cases, the entire field would be devastated within a month. In most cases, this was accompanied by symptoms such as necrotic lesions as small patches adjacent to major lateral veins and necrotic lesions and spots both on the emerging leaf and older leaf sheaths, typical of potassium (K) deficiency. Hence, crop failure was suspected to be due to multiple interaction of limited nutrients in the soil.

Because poor yield due to one or more nutritional disorders results in a poor net return to the farmers, identification, confirmation, and correction of these disorders are of considerable benefit, considering the regional economic importance of the crop. Hence, to fix the optimum nutrient rate and the limiting nutrients for soils growing tuber crops, some preliminary investigations were carried out as a prelude to diagnosing and delineating the soil factors affecting the growth and yield of tannia in these soils.

Materials and Methods

Though the primary objective of the study was to determine the optimum nutrient rate along with identification of marginal nutrients in tuber crops growing in Ultisols, the ultimate practical goal was to diagnose and delineate the soil nutritional problems affecting the growth and yield of tannia. The methodology adopted to achieve these objectives consisted of a preliminary rate trial (PRT) and a nutrient-omission pot trial (NOPT) using maize as an indicator crop (Asher and Grundon 1991). Another NOPT with tannia was also undertaken to delineate the specific cause of growth decline in that crop.

Preliminary Rate Trial

The objective of this trial was to standardize the optimum rate of nutrients required for a particular soil and to standardize the basal application of nutrients. The basic treatment for this trial is an "ALL" treatment having a nutrient composition of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), zinc (Zn), and molybdenum (Mo) at 100, 30, 80, 35, 30, 25, 2, 4, and 0.4 kg ha^{-1}, respectively. The different treatments of this trial included 0 ALL, 0.5 ALL, 1 ALL, 2 ALL, 3 ALL, and 4 ALL. The trial was carried out in a completely randomized design (CRD) with six treatments replicated three times for both garden land and paddy soils using maize as indicator crop. Earthen pots 15 cm in diameter were filled with 2.5 kg soil. The details of the quantity of salts containing the nutrients applied for a 15-cm-diameter pot are given in Table 1.

After applying the treatments in the pots plugged with cotton and maintaining the soil moisture at water-holding capacity, 10 seeds of maize (var. DMRF-32) were sown. After germination, each pot was thinned to five plants. The plants were harvested at 50 days after planting (DAP), and the biomass yield on a dry-weight basis was recorded after proper drying of the fresh sample in an oven at 65 ± 5 °C.

Table 1
Quantity of nutrients applied in 15-cm diameter pots in ALL treatment

Nutrient	Rate (kg ha^{-1})	Name of salt	Rate of application of salt (mg per 15-cm pot)
N	100	Ammonium nitrate (NH_4NO_3)	521
P	30	Sodium biphosphate ($NaH_2PO_4 \cdot 2H_2O$)	314
K	80	Potassium chloride (KCl)	293
Ca	35	Calcium chloride ($CaCl_2$)	179
Mg	30	Magnesium chloride hexahydrate ($MgCl_2 \cdot 6H_2O$)	455
S	25	Sodium sulfate (Na_2SO_4)	202
B	2	Boric acid (H_3BO_3)	20.7
Zn	4	Zinc chloride ($ZnCl_2$)	15.1
Mo	0.4	Ammonium molybdate [$(NH4)_6MO_7O$]	9.37

Nutrient-Omission Pot Trial

The objective of this trial was to identify and delineate the marginal nutrients in a particular soil. From the PRT, the optimum rate required for the particular soil was obtained and that was utilized as the optimum for this trial. This trial was also carried out in both garden land and paddy soils with 10 treatments replicated three times in a complete randomized design (CRD) using the same maize variety following the procedure as above in the PRT. The treatments were optimum (Opt), optimum N, optimum P, optimum K, optimum Ca, optimum Mg, optimum S, optimum B, optimum Zn, and optimum Mo. The crop was harvested at 50 days after planting (DAP) and the biomass yield was recorded on a dry-weight basis. Manifestation of symptoms in maize due to omission of the different nutrients was also monitored.

Nutrient-Omission Pot Trial with Tannia as Test Crop

To further confirm the soil nutritional problems hindering the growth of tannia under acidic soil conditions, NOPT was conducted as a diagnostic tool for foliar diagnosis (Asher and Grundon 1991). This procedure was followed with 2 ALL and 4 ALL, respectively, as the optimum treatment for garden land and paddy soils based on PRT (John and Suja 2006). The 10 treatments imposed in this study were the optimum and the nutrients omitted from the optimum. Tannia cormels of 50–100 g were planted in fiberglass pots 10 days after applying the treatments. Observations were recorded for symptom expression periodically from the first month up to the sixth month, and correspondingly the nutrient contents (viz., N, P, K, Ca, and Mg) in the lamina and petiole showing the symptoms were also analyzed (Piper 1970).

Preliminary Evaluation of the Nutrient Status of the Soil in the Pots

An initial evaluation of the nutrient (pH, major nutrients, secondary nutrients, and micronutrients) status of the garden land and paddy soils utilized for the three trials was done using standard analytical procedures (Jackson 1978).

Results and Discussion

Preliminary Rate Trial

Rate trials are useful in selecting appropriate rates of nutrients to be utilized. The biomass yield of maize recorded at 50 DAP is given in Table 2.

Statistical analysis of the data indicated that with the paddy soil, the biomass yield of maize was significantly greatest with 4 ALL (37.097 g pot^{-1}), whereas in the garden land soil although 4 ALL recorded the greatest dry biomass yield (33.407 g pot^{-1}) it was on par with 2 ALL (26.43 g pot^{-1}). Hence, 2 ALL in garden soil and 4 ALL in paddy soil were taken as the optimum rates of nutrients. Moreover, the data revealed that between the two soils (i.e., garden land and paddy soil) and also between different treatments within each soil there was a significant difference in the dry biomass yield of maize. Hence, it was concluded that the garden soils required an optimum rate of 2 ALL (N, P, K, Ca, Mg, S, B, Zn, and Mo at 200, 60, 160, 70, 60, 50, 4, 8, and 0.8 kg ha^{-1}, respectively), whereas the paddy soil required nutrients at twice the rate of the garden soils. Hence, this trial was taken as a rough guide to fix the rates of nutrient application for subsequent field trials.

The partial anaerobic condition coupled with acidity that prevailed in the lowland soil might have hindered the availability of the nutrients and hence necessitated an increased need for nutrients in that particular soil. Similar trials of PRT and NOPT were conducted with maize in 19 major soil types of Tonga, where tropical tuber crops are grown (Halavatau, Asher, and Bell 1996) and Western Samoa (Poihega, Yapa, and Asher 1996).

Nutrient-Omission Pot Trial

Nutrient-omission pot trials are very useful in identifying the limiting nutrients in the fields (Loneragan 1970). For example, nutrient-omission pot trials with maize in an Orthoxic Tropuduult and Umbric Tropaquiuult soils of Aiyura and the Eastern Highlands of Papua New Guinea were conducted to identify the nutrients deficient in these soils (Dowling et al. 1996).

The data on biomass yield of maize from NOPT indicated that biomass yield was comparatively better in the paddy soil, and the optimum treatment in the garden land and optimum Zn under paddy soil recorded the greatest biomass yields of 5.697 and 10.077 g pot^{-1}, respectively. In the garden land, the biomass yield obtained from all other treatments, except N, P, K, Ca, B, Zn, and Mo (omitted from optimum), were significantly

Table 2
Dry biomass yield of maize (g/pot)

Treatments	Paddy land	Garden land
0 ALL	14.117	10.303
0.5 ALL	25.407	16.553
1 ALL	18.640	15.140
2 ALL	30.040	26.430
3 ALL	12.600	31.997
4 ALL	37.097	33.407
CD (0.05)	6.829	14.487

Table 3
Dry biomass yield of maize (g/pot)

Treatments	Garden land	Paddy land
Optimum	5.697	8.832
Optimum N	0.817	4.607
Optimum P	1.543	2.083
Optimum K	1.897	1.237
Optimum Ca	1.720	6.357
Optimum Mg	5.043	6.790
Optimum S	5.227	4.697
Optimum B	1.520	4.019
Optimum Zn	2.703	10.077
Optimum Mo	2.833	3.473
CD (0.05)	1.245	2.873

superior and on par. In paddy soil, N, P, K, S, B, and Mo were limiting, as the biomass yield obtained with these nutrients omitted was significantly lower compared to the best treatment as well as the optimum treatment (Table 3).

The biomass yield from NOPT revealed that N, P, K, B, and Mo were deficient in both soils; in addition, Ca and Zn in garden land and S in paddy soils were limiting. These nutrient constraints may be attributed to the specific properties of laterites belonging to the soil order Ultisol, which are characterized by a number of limitations including the presence of toxic concentrations of aluminum (Al) and manganese (Mn) and deficiency of essential nutrients (viz., P, Ca, Mg, and Mo). The susceptibility of Ca^{2+} and Zn^{2+} ions to leaching under tropical situation is due to comparatively high rainfall, which may have resulted in the marginal status of these nutrients in garden lands. The low availability of S in paddy soils may be due to its partially anaerobic environment, which might have reduced the availability of S due to relatively low levels of organic-matter mineralization to sulfate (Trangmar 1992) as well as the poor S content in the parent materials. In addition, the rapid solubility of Al^{3+} ions under acidic conditions might have caused nonavailability of essential nutrients in general, thereby affecting the growth and yield of crops like tannia, which are sensitive to acidity.

Nutrient-Omission Pot Experiment with Tannia

The analytical data of the soil filled in the fiberglass pots (mean values) for this experiment are given in Table 4.

Both upland and lowland soils were extremely acidic, and other properties were almost similar to the soil used in NOPT with maize. The nutrient concentrations in the leaves of tannia (lamina + petiole) with omission of different nutrients are presented in Table 5.

The contents of omitted nutrients were less than critical levels in all the leaves, where the respective nutrients were avoided. However, the interaction of K with Mg and K with Ca in oats (Ohno, Grunes, and Sanchirico 1985) as well as the synergy of N, P, and Mg as observed in wheat (Skinner and Matthews 1990) was also evident under the present study, which further corroborates the findings in yams (O'Sullivan and Jenner 2006).

Table 4
Nutrient status of the soil used for NOPT in tannia (mean values)

Soil type	pH	Organic C (%)	Available			Exchangeable		Available			
			N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (meq 100 g^{-1})	Mg (meq 100 g^{-1})	Cu (meq 100 g^{-1})	Fe ($\mu g\ g^{-1}$)	Mn ($\mu g\ g^{-1}$)	Zn ($\mu g\ g^{-1}$)
Garden land	4.82	0.643	164.32	18.49	192.80	1.284	0.643	0.57	29.68	24.54	1.29
Paddy land	4.69	0.703	179.48	22.32	167.36	1.321	1.321	0.71	32.15	25.97	1.51

Table 5
Nutrient content in the leaves of the nutrient-omitted plants of tannia

	P (%)		K (%)		Ca (%)		Mg (%)	
Treatments	Paddy land	Garden land	Paddy land	Garden land	Paddy land	Garden land	Paddy land	Garden land
Opt	0.718	0.610	1.020	0.756	0.535	0.756	0.824	0.503
Opt N	0.451	0.421	2.512	2.990	0.896	0.990	1.191	0.802
Opt P	0.349	0.465	2.106	2.538	0.705	0.538	0.770	0.882
Opt K	0.286	0.228	0.528	0.486	0.349	0.486	0.969	0.855
Opt Ca	0.718	0.523	1.782	1.390	0.389	0.390	0.540	0.963
Opt Mg	0.614	0.473	2.572	1.498	0.551	0.698	0.205	0.414
Critical level	0.50		2.3		0.90		1.3	

Table 6
Nutrient content in the symptom-manifested leaves of tannia (mean of upland and lowland soils)

Leaf portion	N	P	K	Ca	Mg
Petiole (initial stage)	1.6	0.581	0.238	0.763	0.711
Petiole (middle portion)	1.8	0.573	0.380	1.00	0.737
Leaf blade (initial stage)	—	0.448	0.234	0.615	1.185
Leaf blade (slightly severe)	—	0.469	0.65	0.565	0.260
Dried leaf blade	—	0.676	0.55	0.513	0.223
Symptom very severe	—	0.485	0.98	0.416	0.635
Critical level	3.2	0.5	2.3	0.9	1.3

Though symptoms characteristic of the omitted nutrients were observed, specific disorders in the leaves typical of K, Ca, and Mg deficiencies as observed in field conditions, causing the complete devastation of the crop, were also obtained in this study. The typical disorders seen were K-deficiency symptoms in the form of drying followed by necrosis of the tips and margins of older leaves. Calcium deficiency as crinkled and curled upper young leaves and Mg deficiency as interveinal chlorosis of the lower leaves were observed in pots, where these nutrients were omitted from the optimum. The chemical analysis of the lamina and petiole for major and secondary nutrients at different stages of symptom manifestation are presented in Table 6.

The data showed that K, Ca, and Mg concentrations in the different leaf parts at the different stages of symptom expression were low compared to their respective critical levels. The nutrient concentrations of K, Ca, and Mg in the leaf parts of the nutrient-omitted treatments of both garden land and paddy land soils as well as the deficiency symptoms characteristic of each nutrient observed agrees with the fact that the problem is linked to abnormalities in the proper absorption of K, Ca, and Mg by tannia, affecting its growth and yield and associated with soil acidity. This is partially in conformity of the report that in acidic soils such as Ultisols, which are extremely acidic, the potential acidity due to Al^{3+} ions can be toxic to roots, causing injury and hindering the uptake of water and nutrients, especially Ca and Mg (O'Sullivan, Asher, and Blamey 1996).

It has already been established that *Xanthosoma* sp. is considered a good indicator of Mg deficiency (Cable 1979). Hence, this trial gave an indication that the problem is associated with soil acidity and has consequences for Mg-sensitive crops such as tannia. Having understood the nutritional problems associated with the growth and productivity of minor tuber crops like taro and tannia in the acidic soils in different parts of the world, some research efforts were made in Ultisols to correct the problem with different soil amendments such as calcite, dolomite, and gypsum in Costa Rica in taro (Salas and Molina 1996). Efforts also were made to induce deficiency and toxicity symptoms under hydroponic solutions (Miyasaka, Hamasaki, and Pena 2002) and to study the effect of Mg on taro growth (Austin, Constantinides, and Miyasaka 1994).

Preliminary Evaluation of the Nutrient Status of the Soil Filled in Pots

Soil analyses are potentially the most useful and prognostic tests, which can provide timely information to take corrective measures, if needed. The chemical properties of the soil filled in the pots are given in Table 7. The data indicated that there was little variation between

Table 7
Nutrient status of the soil in the earthen pots for PRT and NOPT

			Available			Exchangeable		Available			
Soil type	pH	Organic C (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (meq 100 g^{-1})	Mg (meq 100 g^{-1})	Cu (meq 100 g^{-1})	Fe (μg g^{-1})	Mn (μg g^{-1})	Zn (μg g^{-1})
Upland	5.30	0.779	237.91	16.34	173.81	1.559	0.693	1.40	80.25	6.43	2.54
Lowland	5.38	0.664	195.92	19.84	121.23	1.417	0.509	1.30	30.52	12.94	1.98

the garden land and paddy soils, and compared to paddy land soils, garden land soils were better supplied with major, secondary, and micronutrients.

The soil analytical data indicated that both these soils were acidic, with other nutritional constraints such as medium organic C, low N, medium to high P, and medium K. As regards the critical level (Dev 1997), both garden land and paddy land soils were deficient in Mg and sufficient in Ca and micronutrients (viz., Fe Cu, Mn, and Zn). The infertility of acidic soil is a major problem throughout many tropical regions as they are characterized by one or more of these problems (Sanchez and Logan 1992). The initial nutrient status found in this preliminary evaluation trial is in accordance with the fact that the laterite soils of peninsular India were highly acidic with poor total N, organic C, low available P, and exchangeable K, Ca, and Mg but with greater amounts of Fe, Al, Zn, and Mn (Koshy and Thomas 1972). Nitrogen was the most frequently deficient nutrient in tropical soils (Sanchez 1976) as a result of leaching losses following application of soluble N fertilizers and rapid decomposition and mineralization of organic matter under high temperature and precipitation (Tisdale et al. 1993). The combination of strong P fixation and poor supply of P from parent materials probably explains the severe P deficiencies observed in these soils (Widdowson 1992). Poor K availability in these soils can be due to leaching loss from high rainfall and high soil acidity, which can either retard the release of K or favor its fixation. The increased solubility of micronutrients at low pH can be the reason for the satisfactory availability of micronutrients in these soils (Macdonald 1948).

Conclusions

The basic studies conducted to diagnose and delineate the soil-related crop nutritional problems affecting the growth and yield of tannia resulted in the determination of optimum rates of nutrients as well as the constraint nutrients for tropical tuber crops in garden land and paddy land situations. The nutrient-omission pot trial carried out specifically with tannia to identify and confirm the problem indicated that it was due to a multinutrient disorder of three basic cations (viz., K, Ca, and Mg) coupled with soil acidity. Considering the economic value as well as the nutritional qualities of the crop in relation to human nutrition and health, it is time to exploit the virtues of this underutilized crop. To achieve this, evolution of an integrated nutrient-management strategy to overcome the present nutritional constraints and sustain the crop in the acidic laterite Ultisols of India is under way.

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