DEVELOPMENT OF DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM (DRIS) IN BLACK PEPPER (*Piper nigrum* L.) IN RELATION TO YIELD AND QUALITY CHARACTERISTICS

By

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THESIS

Submitted in partial fulfilment
of the requirement for the degree

DOCTOR OF PHILOSOPHY

Faculty of Agriculture
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1998

DECLARATION

I hereby declare that this thesis entitled **"Development of Diagnosis and Recommendation Integrated System (DRIS) in black pepper *(Piper nigrum L.)* in relation to yield and quality characteristics"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or any other similar title, of any University or society.

Vellanikkara
28th Aug, 1998

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ACKNOWLEDGEMENT

I wish to place on record my deep sense of immeasurable gratitude and unboundful indebtedness to **Dr. N. Neelakantan Potty**, Chairman of the advisory committee and Professor of Agronomy, Kerala Agricultural University, for his invaluable guidance, untiring interest and immense help rendered throughout the course of this investigation. I consider myself to be fortunate to have an association with him, who inspired me with his great wisdom, original thinking,fruitful discussions and brilliant conclusions which led to the accomplishment of this thesis.

I take this opportunity to express my sincere gratitude to **Dr. E. Tajuddin**, Director of Extension (Retd.), Kerala Agricultural University, for the timely help and valuable guidance extended to me during the early part of this investigation.

I am greatly privileged to acknowledge my sincere thanks and indebtedness to **Dr. R. Vikraman Nair**, Professor and Head, Department of Agronomy, College of Horticulture, Vellanikkara, **Dr. P.A. Wahid**, Associate Dean, College of Agriculture, Pilicode, **Dr. P.V. Prabhakaran**, Professor and Head, Dept. of Agrl. Statistics, College of Horticulture, and **Dr. K. Kumaran**, Associate Director, Kerala Agricultural University for their constant encouragement, valuable suggestions and immense help as Members of advisory committee and for critically going through the manuscript.

It is with great pleasure to record my heartfelt thanks to **Sri. C.S. Gopi**, Associate Professor (SS & AC) for his sincere advice, constant support and analytical help extended to me throughout the study.

I am thankful to the staff members of RARS, Ambalavayal, and Agronomic Research Station, Chalakudy, for providing the necessary help and facilities for the collection of samples and for the conduct of laboratory analysis.

I am really grateful to **Ms.** Rema for assisting the laboratory analytical work at ARS, Chalakudy, and to Sri. Rajendra Prasad for his help in AAS estimation at Vellanikkara.

I thankfully acknowledge Sri. C.E. Ajithkumar, Computer Programmer, College of Agriculture, Vellayani for rendering his help in the statistical analysis of the data.

I owe my sincere gratitude to Dr. P.S. John, Dr. Mercy George, Dr.K.E. Savithri and other faculty and staff members of the Dept. of Agronomy for their help, assistance and co-operation during the course of this study.

I am thankful to Sri. M.C. Devassy, ARS Chalakudy , for his sincere help in computerised type setting of this thesis.

I am also thankful to Dr. T.I. Mathewkutty, Sri. P.G. Mathew, Sri. Ajithkumar, Dr. K.C.Aipe, Dr. Manomohandas , Dr. K.N. Anith, Sri. Krishnan, Ms. M. Rema Devi, Sri. V.K. Rajendran and Sri. K.S. Joseph for their timely help at various stages for the successful completion of this project.

I lovingly acknowledge the great deal of co-operation, inspiration and support from my wife Subhadra and son Arvind throughout the course of this study.

I am also grateful to the Kerala Agricultural University for granting me study leave for pursuing the studies.

V. SREEKUMARAN

CONTENTS

ABBREVIATIONS

DRIS	-	Diagnosis and Recommendation Integrated System
SD	-	Standard Deviation
CV	-	Coefficient of Variation
LYG	-	Low Yield Group
MYG	-	Medium Yield Group
HYG	-	High Yield Group
NII	-	Nutrient Imbalance Index
MSL	-	Mean Sea Level

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INTRODUCTION

INTRODUCTION

Black pepper (*Piper nigrum* L.) is the "Golden vine" of the West Coast of India. Intertwined with the history, economy and specialities of climate of the region, black pepper still enjoys the primary position as the most alien demanded as well as the maximum revenue earning agricultural commodity of this region. This precious spice is an inevitable Orient dependant dietary necessity of the West. Very poor productivity of the order of 0.28 kg plant^{-1} as against 4.0 kg in Thailand (Anon, 1997), disease problems, inadequate management technology and inflationary trends in inputs on the one side, and attractive adoption in the South East Asia are fast eroding our primacy and monopoly on this crop. This situation warrants immediate and objective intervention for yield improvement. Presence of few plants yielding well above 10 kg plant^{-1} in every plantation is sufficient proof that tremendous yield improvement is possible with little increase in input cost. Even an enhancement of the yield level to one kg plant^{-1} can straighten agrarian economy and restore our monopoly on this crop. Nutritional management naturally assumes precedence in productivity improvement in perennial crops like black pepper as breeding measures are cumbersome and time consuming.

Genic variability is often attributed as the cause of extreme plant to plant variation in yield expression in perennial crops. Mathewkutty (1994) estimated this variability in the order of 6 to 120 nuts palm^{-1} year^{-1} in coconut. Being a vegetatively propagated crop such extreme variability is not to be expected in black pepper especially as the crop is under the same management. Observations to the contrary (Mathew, 1993) are suggestive of the fact that blind adoption of conventional management technology may not succeed in the case of perennial crops, and calls for a critical reappraisal of the entire concept of nutritional management.

Perennial crops are characterised by a confined and limited feeding zone to be depended upon for several years and their yield expression is a net integrated effect of previously accumulated potential and currently acquired capabilities. Thus varying levels of growth and yield pressures make every plant a unique soil-plant system. Thus it is likely that conventional soil based analysis will become insufficient to explain the yield process or yield expression of this crop.

It is often the quality that defines a crop and its product. Black pepper is valued for its oleoresin content which varies between 6.4 and 25.7 per cent (Mathai *et al*, 1980). The biomass yield and quality are not the resultants of a single but sequential processes and their nutritional requirements are also not the same. Moreover, there tends to be negative interrelations between qualitative and quantitative yields (Menon, 1996). These trends point out to the fact that exclusive dependence on the critical level of any one or two elements may not be sound or scientific.

It is well known that elements interact among themselves and hence growth and yield processes are the net product of the interacting influences of all the elements involved. Moreover, soil contains many minerals other than essential or functional ones which will interact with the required ones. These interactions may modify the efficiency levels of every element's effort to relate productivity to individual elements or their levels, is likely to be scientifically not perfect. This is particularly important under our conditions where influence of the native content of elements like Fe and Mn as well as their interactions are expected to be of a high order.

As these call for a nutritional management system which takes in to account the contents of as many elements, as well as their interactions and balance in relation to yield and quality, and also considers the yield as the product of soil-plant system.

Diagnosis and Recommendation Integrated System (DRIS) developed by Beaufils (1973) is such a system. It has the unique advantage that it tries to simulate the nutritional situations of the high yielding plants into the low yielding ones and considered nutritional balance. However, Mathewkutty *et al.* (1998) had reported that the DRIS failed to diagnose the response to N and P in coconut. They had suggested utilisation of DRIS approach to supplement the critical level concept. Doubts on the viability of the system have also been cast by Mathewkutty (1994).

Thus the absence of a fool-proof and proven system that can be adopted calls for an indepth reappraisal of all the available approaches, and evolving either a modified or a new viable technology based on scientific soundness and reliability.

The broad objectives can be listed as follows.

i) To study the nature and magnitude of relationships of foliar nutrient levels with yield and pungent principle.

ii) To compare the critical level concept and DRIS method in nutrient deficiency diagnosis, and,

iii) To develop DRIS reference norms for major, secondary and micronutrients for diagnosis of nutrient balance, nutrient deficiency and nutrient excess in black pepper.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Nutritionl management has been recognised as important as plant improvement in increasing crop productivity. Efficacy of nutritional management depends up on identifying the limiting influences and alleviating them. Generally confined to the source, level, time and frequency of application of major elements; fertiliser management is based on soil available nutrient level and critical level concept, and is crop specific. Beaufils (1973) proposed the concept of DRIS as a better tool for specific corrections of yield limiting factors. Information available on fertility management, their guiding principles and efficacy on black pepper has been reviewed here.

2.1. Nutritional management of black pepper

Systematic nutritional management studies in black pepper had been comparatively of recent interest. Harden and White (1934) and Bergman (1940) reported burnt ash as the manure for pepper in virgin land which had a high pH and CaO content and exerted a three pronged effect of reducing acidity, supply of nutrients and improving the physical condition of soil. Acidity of soil had remained the most harmful effect of soil as has been reported by Marinet (1953), De Waard and Sutton (1960), De Waard (1978),and Purseglove *et al.* (1981). Sim (1972) found that high content of Mn in plants the cause of physiological disorder in black pepper.

Scientific nutritional management considers nutrients lost in produce as a guideline for fertiliser management.

2.1.1. Nutrient removal in black pepper

From the results of the experiment on the nutrient removal in black pepper, De Waard (1964) concluded that the variety Kuching with a plant population of 1729 vines ha^{-1} removed 252.04 kg N, 31.75 kg P_2O_5 and 224.04 kg K_2O. De Waard (1969) also proposed the critical levels of N, P, K, Ca and Mg as 2.7, 0.10, 2.00, 1.00 and 0.20 per cent, respectively, on dry weight basis, below which deficiencies of the concerned elements were expected to develop.

According to Sim (1971) the nutrient removal by 17 year old pepper vines was 233 kg N, 39 kg P_2O_5, 207 kg K_2O, 30 kg MgO and 105 kg CaO per hectare.

In a study to find out the removal of micro nutrients from the soil, Sim (1973) reported an yearly removal of 365 mg Fe, 281 mg Mn, 104 mg Zn, 89 mg Cu and 60 mg B by each mature vine in Sarawak.

It was concluded from the fertilizer experiment in black pepper laid out at Panniyur, Kerala, that one hectare of pepper garden having a plant population of 1200 vines yielding on an average 1 kg dry pepper per vine removed 34.0 kg N, 3.5 kg P_2O_5 and 32.0 kg K_2O per year (Pillai and Sasikumaran, 1976). Based on this, they had recommended a manurial schedule of 100 g N, 40g P_2O_5 and 140g K_2O $vine^{-1}$ $year^{-1}$.

The results of the fertilizer experiment conducted in black pepper var. Panniyur-1 revealed that higher levels of N encouraged luxuriant vegetative growth and thereby affected the yield (Pillai *et al.,* 1979). They, therefore, recommended 60 g N $vine^{-1}$ $year^{-1}$ as the maximum limit for proper growth and production of crops.

In a study on the nutrient removal and its distribution in the plant parts, Sankar (1985) found that the annual nutrient removal by a five year old vine through harvest of 1.284kg dry pepper was 38.5g N, 36.7g K, 14.9g Ca, 13.7g Mg, 2.2g P, 1.37g S, 218mg Fe, 55mg Mn, 48mg Cu and 28mg Zn.

Mathew *et al.*(1995) reported that 14 year old Panniyur-1 vines removed 6.35g N, 0.44g P, 6.33g K, 1.11g Ca, 0.47g Mg, 0.29g S, 42.89mg Fe, 4.28 mg Zn and 34.45mg Mn for every one kg of harvested produce. The magnitude of nutrient removal by harvested produce followed the decreasing order N > K > Ca > Mg > P > S > Fe > Mn > Zn.

Sivakumar and Wahid (1994) observed an average nutrient removal of 200.19 mg N, 18.92 mg P, 432.53 mg K, 155.89 mg Ca, 19.44 mg, 12.33 mg S, 1517 g Fe and 3546 g Mn by 6 month old black pepper to produce 11.19 g total dry matter.

2.1.2. Nutrient elements and productivity

Leaf composition of black pepper has been subjected to detailed analysis by different workers. Bataglia *et al.* (1976) found that N was maximum at autumn, but declined in winter, and P and K were maximum in summer.

Geetha (1981) observed that flowering laterals gave a higher content of N, P and K than other at flowering and shoot development stage. They tended to decline after November. Kurien (1982) failed to get the above trend in the case of both N and P but confirmed the same in the case of K.

Wahid *et al.* (1982) in their study on the mineral nutrition of slow wilt affected pepper had not found any difference in micronutrient level in the leaves of pepper, although the healthy leaves contained more of K than the unhealthy ones.

Investigating the relationship of leaf nutrient content to productivity, Sushama, *et al.* (1984) reported significant positive correlation of yield with P and K of leaf, whereas the N content failed to establish significant positive correlation with yield.

Nybe and Nair (1986, 1987a, 1987b, 1987c) and Nybe *et al.* (1988) could induce deficiency symptoms of macro and micro nutrients by sand culture experiments in Kerala. Deficiency symptoms of macro nutrients except Ca and S were first manifested on the older leaves. Symptoms of N deficiency was expressed as uniform yellowing followed by necrosis, whereas purple to bronze yellow colour and ash coloured necrotic areas were the symptoms of P deficiency. K deficiency was characterised by tip and marginal necrosis which later progressed to the distal 2/3 portion of the lamina. Vegetative growth was considerably reduced due to deficiency of macro and micronutrients. Ca, P, N and S showed profound influence on shoot growth. Visual symptoms of deficiencies were concurred with a marked reduction in the foliar level of concerned element. The deficiency symptoms could also be recovered by the application of the deficient nutrient element and thus the deficiency of the element was confirmed.

From the results of the long term fertilizer experiment in black pepper at Panniyur in Kerala, Nybe *et a.l.*(1989) concluded that the foliar levels of N,K, Ca and Mg increased when fertilizers were applied during rainy season. The nutrient elements P, K, Ca, Mg and S were found to exert direct and indirect effect on yield of green pepper. Of these P and K were found to be of greater importance in enhancing the yield.

Sadanandan *et al.*(1991) observed significant positive correlation between yield and leaf N in Panniyur-1 cultivar of black pepper. Geetha and Aravindakshan

(1992) studied the influence of levels of NPK on growth and dry matter production in bush and vine pepper. They found that increasing levels of N, P and K resulted in significant increases in several growth parameters and dry matter yield components in both bush and vine pepper.

Cheeran *et al.* (1992) in their study on the effect of variety, spacing and support material on nutrition and yield of black pepper observed that the variety Karimunda accumulated more K, Ca and Mn in the leaf compared to Panniyur-1. They also found a depressing effect of Ca content on yield.

2.2. Interaction of elements in crops

Equally important as the content of the element in the plants is the status of every element in relation to another. This is because of the interaction among elements which includes competition based on bonding strength, ion nature and relative contents.

An interaction occurs when the response of one or a series of factors is modified by the effects of one or more factors. When the response to two or more nutrients used together is greater, less or equal than the some of their individual response, a positive, negative and no interaction, respectively, is said to have occurred.

Terman *et al.* (1977) reported that N-P interaction effects on yield are primarily attributable to N induced increase in P absorption by the plants. Biswas and Prasad (1991) suggested that at higher levels of N and P no further increase in pod yield of ground nut was possible due to high native fertility of the soil.

Wahid *et al.* (1977) found positive significant correlation between P and K contents of 14th leaf in coconut. Studies by Ganiron *et al.* (1969) with corn in the field showed that addition of P to a P sufficient soil will not stimulate growth but may in fact significantly reduced yield as a result of a P induced Zn deficiency.

Boawn and Leggett (1964) reported that Zn and P appeared to be mutually antagonistic whenever either element exceeded some threshold value. Mehta and Singh (1988) reported that higher levels of Zn reduced P uptake significantly over control in mustard.

The interactions between P and Fe indicate that the process is not very simple, being complicated both by the level of acidity or alkalinity in the soil material and the nature of the rhizosphere of the particular crop. The great affinity between Fe and P both in the soil and in the plant can severely complicate any attempt to explain the P-Fe interaction because the insoluble products formed can precipitate or be chemisorbed in the soil after addition or during the translocation and assimilation process. Ayed (1970) opined that the concentration of Fe-P in tomato roots in nutrient solution was eight to ten times higher than in the tops due to iron phosphate precipitated in roots.

Mehta and Singh (1988) reported that S and Zn application augmented the utilisation of N and K by mustard plants. Jackson *et al.* (1967) found that when P needs of sweet corn were met, Zn deficiency became dominant and plants contained high levels of Fe. Addition of Zn increased growth and led to a marked reduction in Fe concentration in plants.

Warnock (1970) measured a relationship between P induced Zn deficiency in corn and the concentration and mobility of Fe and Mn within the plant. The relative mobility of Fe and Mn was inversely related to the mobility of Zn.

Fe and Mn are interrelated in their metabolic function with the effectiveness of one determined by the proportionate presence of the other.

Grasmanis and Leeper (1966) reduced toxic Mn levels in apple leaf by injecting iron citrate into the tree or by applying Fe EDTA to the soil.

Mitra *et al.* (1990) reported that application of additional level of K fertiliser resulted in an increase in yield of rice grown in an Fe toxic soil, while, Dev (1993) found a reduction in Fe uptake and Fe/K ratio in such situation.

Prabhakumari (1992) observed antagonistic relationship of elements in coconut between N x Cl, P x Cl, P x Zn, P x Cu, P x Fe, K x Fe, K x Ca, K x Mg, Ca x Zn, Mg x Fe, Mg x Cu, S x K, S x Mo, S x Cl, S x B, Fe x Mn, Fe x Mo, Mn x Mo and Cu x Mo. The synergism observed were N with Fe, Cu, P and S; P with Ca, Mg, S and Mo; K with Mn and B; Ca x Mg, Mg x Mo, S with Fe, Mn, Zn and Cu; Cl with Mn and B and Fe x Zn.

Mathew (1993) reported synergistic interaction of P x S and Ca x Mg in black pepper. He also found that foliar K maintained negative correlation with foliar Mg indicating the antagonistic effect between mono and divalent cations.

2.3. Quality characteristics of black pepper

The pungent principles of black pepper have been the subject of a series of investigation since the early 19th century. The most abundant alkaloid, piperine, was first isolated by Oersted in 1820.

The quality of black pepper is generally evaluated on the basis of its physical, chemical and organoleptic properties of which the bulk density, colour, boldness, contents of volatile oil, non-volatile ether extract (NVEE) and piperine content are the commercially more important parameters. The bulk density value of pepper is an indicator of the levels of maturity and its starch content. The volatile oil of black pepper is responsible for the aroma, and its pungency is due the contents of piperine and NVEE. The sensory value of pepper is related to the combined effect of, and the balance between its aromatic spiciness and distinctive pungency (Govindarajan, 1976).

Extraction of black pepper with organic solvents provides an oleoresin possessing the odour, flavour and pungent principles of the spice. The organoleptic properties of the oleoresin are determined by its volatile oil and piperine contents, and the abundance of the components is principally dependent on the raw material used for extraction..

Piperine is undoubtedly accepted as the major pungent principle of pepper and probably consists of over 95 per cent of the total pungent alkaloids present in pepper (Purseglove *et al.,* 1981).

2.91.

The piperine content in pepper berries generally varied from 29.0 to 11.0 per cent for Panniyur-1 and 3.0 to 5.7 per cent in Kuching varieties at six months maturity. The range of values for the NVEE content in Panniyur-1 and Kuching cultivars were 6.8 to 13.5 per cent and from 6.2 to 7.7 per cent, respectively, whereas the volatile oil content varied from 1.3 to 3.5 and from 1.0 to 2.7 per cent respectively (Genest *et al.* , 1963; Pruthi, 1970; Jose and Nambiar, 1972; Poulose, 1973; Govindarajan, 1976; Rathnawathie and Lewis, 1983 and Rathnawathie, 1984). Nambudiri *et al* . (1970) reported that the content of oleoresin varied from 10 to 13 per cent in Indian Malabar pepper.

The piperine content in oleoresin was reported to vary from 25 to 55 per cent (Mathai, 1981; Jansz *et al.* ,1984). Nambudiri *et al.*(1970) reported that acetone was the best solvent for the extraction of pepper oleoresin. A coarse powder of 0.3 mm size allowed easy draining of solvent and gave satisfactory yield of oleoresin.

Games *et al.*, (1984) identified a series of N - isobutyl trienamides and dienamides, together with piperettin and piperine isomers, and piperolein A and B, piperamine and piperylin compounds from the oleoresin of black pepper. According to Sikka *et al.*, (1984), the essential oil content ranged from 0.9 to 3.8 per cent and that of oleoresin from 2.25 to 10.92 per cent in black pepper varieties.

Geetha and Nair (1990) observed that oleoresin content was highest (14.21 percent) when NAA was applied at 150 ppm in black pepper. Borges and Pino (1993) reported maceration of berries before extraction by alcohol for faster and increased recovery of oleoresin than by soxhlet method.

Mc Carron *et al.*, (1995) in their comparative study of green and black pepper oils found that the essential oils obtained by hydrodistillation were similar in monoterpene hydrocarbons, but differed with regard to their sesquiterpene and oxygenated components.

Kathirgamathaiyah and Senanayake (1996) studied the quality characters of 10 Srilankan local cultivars and the introduced varieties, Panniyur-1 and Kuching. They found that the Srilankan cultivars showed higher bulk density, piperine content (6.4 to 11.7 per cent) and NVEE (14.0 to 19.8 per cent) than Panniyur-1 and Kuching.

2.4. Diagnosis and Recommendation Integrated System (DRIS)

Diagnosis and Recommendation Integrated System as proposed by Beaufils (1973) has two components, viz. Diagnosis at the plant level and Recommendation at the soil level. Again, Diagnosis part has two components - dividing the population into two sub groups, low and high-yielding sub populations.

2.4.1. Division of reference population

Different criteria had been adopted by different workers. Davee *et al.* (1986) opined that cut off value is not critical as such. They found that what is important is normal distribution in the reference population. However, they took mean ± SD so that differences between low and high-yield sub populations become apparent and discriminatory. Mathewkutty (1994) in coconut followed the mean ± SD to divide the population, while Sadananadan *et al.* (1996) took an arbitrary value of above or below one kg berry yield as the yield cut off in black pepper.

2.4.2. Comparison of DRIS and other diagnostic methods

Different views have been expressed on its utility and superiority over other diagnostic methods.

Sumner (1979) investigated the comparative merits of DRIS with critical level concepts in four field crops, viz. corn, soyabean, sugarcane and potatoes and found DRIS distinctly superior to critical level concepts in diagnostic precision and concluded that the former is the better.

The superiority of DRIS system has also been reported by Langenegger and Smith (1978) in pineapple, Lee (1980) in tea, Grove and Sumner (1982) in sun flower, Chithiraiselven *et al.* (1984) in grapes and Sumner (1985) in citrus and peaches.

Elwali and Gascho (1984) while subscribing to the views of Sumner, reported that the utility of DRIS concept in increasing not only the yield but also the quality of the produce simultaneously in sugar cane.

Bever *et al.* (1984) working on valencia orange and Beverly *et al.* (1986) on soybeans with DRIS system found that it tallied well with sufficiency range method. Comparability of DRIS with critical level concept have been reported by Khan *et al.* (1988) in coconut, Needham *et al.* (1990) in loblolly pine.

Rathfon and Burger (1991a, 1991b) attributed the uniqueness of DRIS to its ability to diagnose the nutrient imbalance in fraser fir christmas trees. They also cited certain limitation in the use of DRIS in some crops, and were identifying a suitable expression of yield, maintaining symmetry in DRIS index equations, and dealing with extremely variable micronutrients. The DRIS symmetry was maintained by including non-significant ratios but setting their standardisation function equal to zero. This reduced the influence of the non discriminating nutrient ratios on DRIS analysis.

Wortman *et al.* (1994) reported that use of DRIS was more accurate than critical nutrient level system for predicting nutrient needs of phaseolus beans and East African high land bananas.

Thomas Varghese (1994) derived DRIS norms for oil palm in Kerala and reported the usefulness of DRIS method over the conventional systems. The study also revealed that the importance of magnesium nutrition in oil palm at higher levels of NPK fertilizer application.

However, in contrast to the above, some workers criticised DRIS as incapable to explain the nutritional significance totally.

The DRIS and critical concentration approach were used to identify mineral nutrient deficiencies in papaya (*Carica papaya* L.) grown under sand culture and field conditions. The results indicated that DRIS neither identify specific fertilisers nor the quantities for correcting nutrient deficiencies (Bowen, 1992).

In an evaluation of mineral analysis of verna lemons(*Citrus limon*(L) *Burm.f.*) by DRIS, Cerda *et al.* (1995) found that DRIS determinations were affected by root stock and date of sampling of leaves. They further stated that this approach failed to reveal under saline conditions if a nutrient deficiency is induced by an excess of salinity or by a deficient fertilisation.

Soltanpour *et al.* (1995) compared DRIS and nutrient sufficiency range approaches for corn, and reported that nutrient sufficiency range was superior to DRIS approach. They suggested the use of nutrient sufficiency range technique in combination with a soil test to avoid the misdiagnosis of Zn and Cu deficiencies in corn when N was extremely deficient.

Mathewkutty *et al.* (1998) was of the opinion that DRIS could not explain the deficiencies and response pattern of nutrients in coconut and as such serve only as supplementary to critical level concept.

2.4.3. Utility of DRIS in perennial crops

Utility of DRIS concept in perennial crops had also been tested by several workers. Hockman *et al.* (1979) and Kopp and Burger (1990) suggested that DRIS concept could be successfully utilised in the nutritional management of fraser fir christmas trees.

Mathewkutty (1994) applied the DRIS concept in his analysis of yield limiting factors of coconut in Kerala. Its utility was also reported by Sumner (1985) in citrus and peaches and Thomas Varghese (1994) in oil palm.

Sadanandan *et al.* (1996) tested in black pepper and reported the unique capability of the system for the whole of a region however diverse it may be.

2.4.4. Sample size and correctness

While supporting the concept of DRIS suggested that the precision of diagnosis will be better if sample size is bigger. Varying sample size has been used by different workers. Hockman *et al.* (1979) used probably the smallest size of 79 plants belonging to fraser fir christmas trees in developing DRIS norms but suggested repetitive work over several years.

Johnson and Sumner (1980) used 745 sets of plants in potato. Payne *et al* (1990) used 857 samples to develop DRIS norms for bahia grass. Mathewkutty (1994) used 800 plants in coconut while Sadanandan *et al.* (1996) utilised 578 plants of black pepper for the purpose.

Prabhakumari *et al.* (1993) tested the efficiency of DRIS approach in predicting nutrient imbalance in coconut and emphasised the requirement of larger population for wider acceptability.

2.4.5. DRIS and regionality

Nutritional management is a localised phenomenon and investigations on the universality of DRIS have also been made.

Walworth and Sumner (1987) developed DRIS norms for alfalfa and reported that some regionality existed. Sumner (1977a) found that the diagnostic norms made out will find applicability irrespective of age of leaf or varieties and accordingly, he developed the norms for wheat and corn (Sumner 1977b and c). This universality is as against variability in leaf composition with age and leaf position as reported by Sushama (1982) and Nybe (1986).

Angeles (1992) observed from Philippines that the advantage of DRIS is that norms developed remained stable irrespective of season, plant age, leaf sections, variety, location or position of leaf.

Evaluating the interaction between soil factor and variability in DRIS methods, Walworth and Sumner (1987) also subscribed that the factor of regionality existed. Parent and Granger (1989) also had questioned the universality of the concept and found year to year variation in norms. According to them DRIS norms may fail to explain cumulative yields. Payne *et al.* (1990) were of the view that some amount of universality existed.

2.4.6. Nutrient Imbalance Index (NII)

Nutrient imbalance index is the summed up value of individual indices. Elwali and Gascho (1984) found that NII significantly decreased in sugarcane when fertilisation was based on DRIS.

Faber *et al.* (1988) observed significant correlation between yield and the total of absolute DRIS indices and between yield and the absolute index value of an applied nutrient in winter wheat. However, contrary to these progressive diagnosis has been reported to increase NII at certain levels though there will be an overall decline in the NII.

Mathewkutty (1994) found that the concept of NII itself is beset with the pattern of an element with another may get masked as balanced and imbalanced.

MATERIAL AND METHODS

3. MATERIAL AND METHODS

The experiment entitled "Development of Diagnosis and Recommendation Integrated System (DRIS) in black pepper (*Piper nigrum* L.) in relation to yield and quality characteristics" was undertaken at Regional Agricultural Research Station, Ambalavayal during 1993-96. Details regarding experimental material and methods employed in the conduct of the study are presented here.

3.1. Location

Regional Agricultural Research Station, Ambalavayal is situated at an altitude of 974 m above MSL and lies between 10^{o} 26' and 11^{o} 59' N latitudes and 75^{o} 46' and 76^{o} 26' E longitudes in the Wayanad district of the state. Black pepper is grown in a plantation scale in the Western Ghats. In Kerala, high ranges contribute maximum production and area under this crop. Ambalavayal is a representative area of pepper plantation tracts in the state and so in the country.

3.2. Climate

Situated 974 m above MSL, the area enjoys a mild sub tropical climate with mean temperature range between 17.4 ^{0} C and 27.3 ^{0} C. The mean annual rainfall is 2293 mm and over 60 per cent of which is received during the South West monsoon.

The weather situation during the period under study was normal and in tune with the annual cycle without any significant variation. The data on the meteorological parameters of the area are presented in Appendix I .

3.3. Soil

The soil of the experimental field is forest loamy type and the rhizosphere environment (Table 4) indicated a medium high to very high status of soil fertility.

3.4. Selection of plants

Black pepper plantation established during 1980 in block no.V of the station was used for the study. The experimental field is located on a moderately sloping terrain. The Panniyur-1 vines (Plate 1) selected for the experiment were of uniform age of 14 years and trailed on silver oak (*Grevillea robusta*) as standard.

The black pepper vines were grown under rainfed conditions and received fertilizers and other cultural management practices as per the package of practices recommendations of the Kerala Agricultural University (KAU, 1993).

One thousand and two hundred vines having wide variation in yield were selected for the study, of which 1100 constituted the reference population and 100 represented the test population.

3.5. Collection of leaf samples

Leaf samples were collected from the 1200 selected vines, following the procedure suggested by De Waard (1969). The sampling was done during May, 1994, just prior to flushing of the vines. The first mature older leaves from the fruit bearing laterals, exposed to sunlight and located on the lower two-thirds of the canopy were collected for the purpose. From each plant eight leaves having uniform size and thickness with petiole intact were collected at the rate of two each from north, south, east and west quarter aspects of the vine. The time of sampling was between 8 am and 12 noon. The leaf samples were cleaned, dried at 70^0 C in a hot air oven, powdered in a mill with stainless steel blades and stored in plastic containers until chemical analysis.

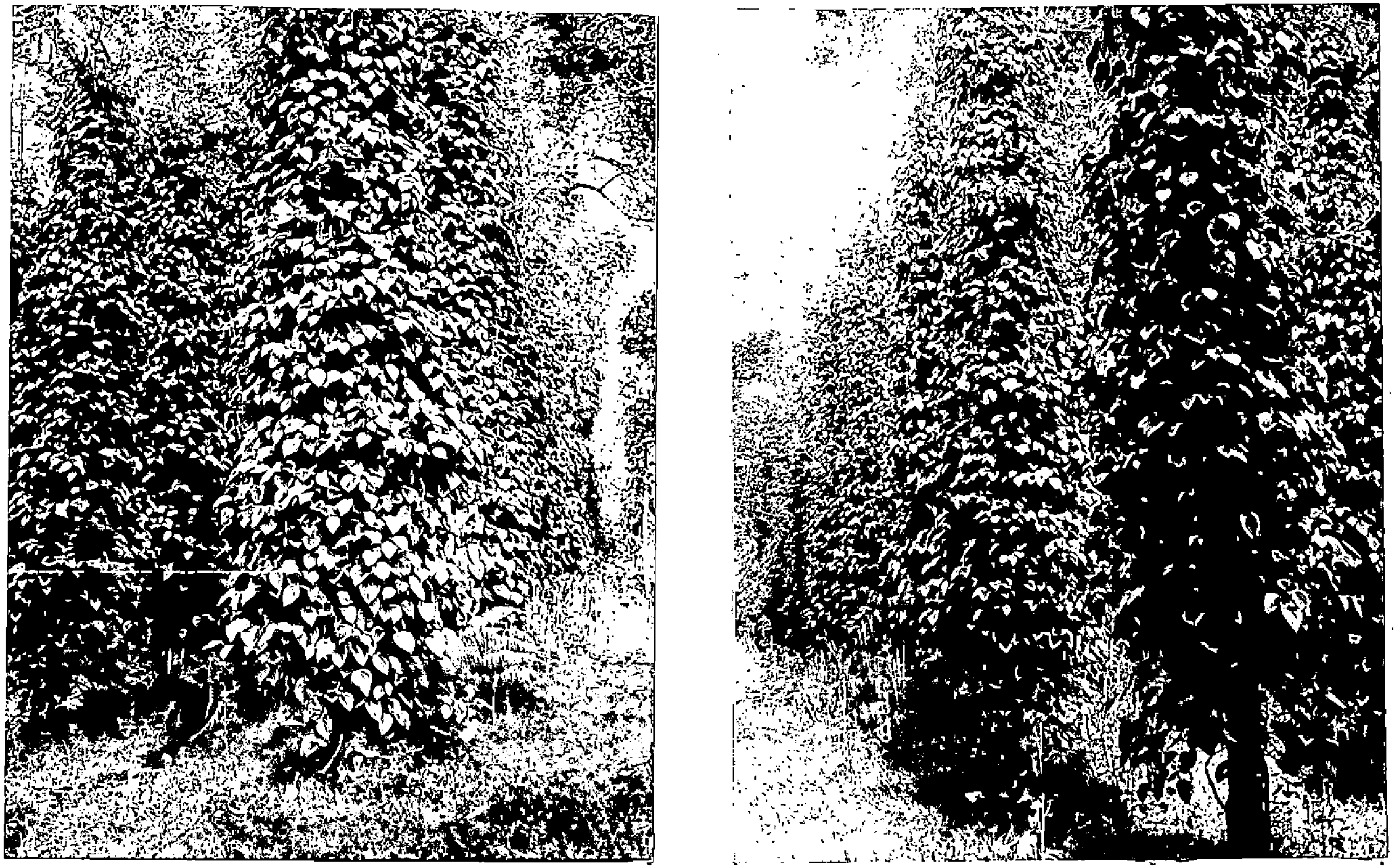

Plate 1 **General view of the experimental plantation**

3.6. Collection of soil samples

The soil samples from all the 100 test plants were collected during May, 1994, just prior to the flushing of the vines. The rootzone samples from 0 to 30 cm depth were collected from four points in the basin 15 cm away from the vine and composited to give a sample. Collected soil samples were air dried, powdered gently and passed through a 2 mm sieve. The samples were stored in plastic containers for further analysis.

3.7. Collection of berries

One thousand two hundred berry samples were collected from both reference and test population. The mature spikes were collected from fruit bearing laterals at random from different quarter aspect of the plant, located on the lower two-third of the canopy. The green spikes were collected at six months maturity during December, 1994. The spikes were dried at $70^{0}C$ in a hot air oven and the berries were ground in a mill with stainless steel blades for the estimation of oleoresin content.

3.8. Yield of black pepper

The harvesting of spikes at full maturity (Plate 2) of the 1200 vines selected was done during February, 1995, and the yield was recorded and expressed as dry yield as kg $plant^{-1}$.

3.9. Analytical methods

3.9.1. Chemical analysis of soil samples

The soil samples were analysed for pH, organic carbon, available P, exchangeable K, Ca, Mg, available S, Fe, Zn and Mn. The analytical procedures employed are summarised in Table 1.

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Plate 2 **Black pepper plants bearing spikes**

Table 1 Details of methods followed in soil chemical analysis

Soil Characteristics	Extractant used	Method of estimation	Instrument used	Reference
pH	1:2.5 soil water ratio	Direct reading	pH meter	Jackson(1973)
Organic carbon	-	Walkley-Black Titrimetric	-	,,
Available P	Bray-1	Ascorbic acid blue colour	Spectronic 20 Photoelectric colorimeter	Watanabe and Olsen(1965)
Exchangeable K	N.Ammonium acetate	Direct reading	Flame Photometer	Jackson(1973)
Exchangeable Ca	,,	,,	Atomic Absorption Spectrophotometer	Jackson(1973)
Exchangeable Mg	,,	,,	,,	Jackson(1973)
Available S	-	Turbidimetric	Spectronic 20 Photoelectric colorimeter	Fox et al,(1964)
Available Fe	0.05N HCl + 0.025N H_2SO_4 at 1:4 ratio	Colourimetric	,,	Jackson(1973)
Available Zn	,,	Direct reading	Atomic Absorption Spectrophotometer	Page(1982)
Available Mn	,,	,,	,,	,,

The pH of the soil was determined at a soil-water suspension ratio of 1:2.5 using a pH meter. Total organic carbon content of soil was estimated by Walkley-Black's method (Jackson, 1973). Available P in the soil was extracted by Bray no.1 extractant and the P content determined colorimetrically by the ascorbic acid blue colour method (Watanabe and Olsen, 1965). Exchangeable K in the soil was extracted using neutral normal ammonium acetate and the K content read in flame photometer (Jackson, 1973).

Determination of exchangeable Ca and Mg was made using ammonium acetate leachate in an atomic absorption spectrophotometer. Available S content in the soil was estimated by turbidimetric method (Fox *et al.*, 1964).

For the determination of available micronutrients Fe, Zn and Mn, the soil samples were extracted with 0.05 N HCl + 0.025 N H_2SO_4 in the ratio 1:4 for 15 minutes. The Fe content in the extract was determined colorimetrically using KSCN (Jackson, 1973). The Zn and Mn contents were read in an atomic absorption spectrophotometer (Page, 1982).

3.9.2. Chemical analysis of plant samples

The leaf tissue samples were analysed for major, secondary and micro nutrients, such as N, P, K, Ca, Mg, S, Fe, Zn and Mn, and the summary of analytical procedures are presented in Table 2.

The total nitrogen content in the plant sample was estimated by Kjeldahl method (Jackson, 1973). For the analysis of other elements, diacid extracts were prepared by digesting 1 g of the same in 15 ml of 2:1 concentrated nitric: perchloric acid mixture (Johnson and Ulrich, 1959). Aliquots of the digest were used for the analysis and estimation of total P, K, Ca, Mg, S, Fe, Zn and Mn.

Table 2 Details of methods followed in leaf analysis

Nutrient	Digestion procedure	Method of estimation	Instrument used	Reference
N	H_2SO_4 digestion	Distillation and titration	Titrimetric	(Jackson 1973)
P	2:1 HNO_3-$HClO_4$ diacid digest	Vanado molybdate yellow colour	Spectronic 20 Photoelectric colorimeter	Johnson and Ulrich(1959) Jackson(1973)
K	,,	Direct Reading	Flame Photometer	,,
Ca	,,	EDTA	Titrimetric	Page (1982)
Mg	,,	EDTA	,,	,,
S	,,	Turbidimetric	Spectronic 20 Photoelectric colorimeter	Hart (1961)
Fe	,,	Colorimetric	,,	Jackson (1973)
Zn	,,	Direct reading	Atomic Absorption Spectrophotometer	Page (1982)
Mn	,,	,,	,,	,,

Phosphorus was determined colorimetrically by vanadomolybdo-phosphoric yellow colour method (Jackson, 1973). Potassium was estimated using flame photometer.

Total calcium and magnesium were estimated titrimetrically by using EDTA (Page, 1982). Sulphur in the digest was determined turbidimetrically following barium chloride method (Hart, 1961). Fe was estimated by phenanthroline method and the colour read in spectrophotometer (Jackson, 1973). Zinc and Manganese in the sample were read in atomic absorption spectrophotometer (Page, 1982).

3.9.3. Estimation of oleoresin content

The oleoresin content in the freshly ground dry pepper was estimated by cold percolation method using acetone as the solvent (ASTA, 1960) and expressed as percentage.

3.9.4. Yield of oleoresin

Yield of oleoresin was worked out by multiplying individual yield of dry pepper of each plant with its respective oleoresin content, and expressed as kg plant^{-1}.

3.10. Statistical analysis

The data on yield of berries, yield and content of oleoresin and soil and foliar analysis of selected plants of black pepper were subjected to statistical analysis for the computation of DRIS norms for yield of berries, per cent content of oleoresin, yield of oleoresin, and DRIS nutrient indices as per the standard methods suggested by Beaufils (1973) and Walworth and Sumner (1987). The relationships between foliar and soil elements on yield and quality characteristics were also worked out.

3.11. DRIS norm for yield of berries

The experimental population of 1100 plants where foliar elemental composition and yield were available constituted the "reference plants".

3.11.1. Norm plants

The norm plants constitute the high-yielding sub population of the reference plants. They are differentiated by dividing the reference plants using mean and standard deviation (SD) into two sub groups viz. low-yielding sub population (mean minus SD) and high-yielding sub population (mean plus SD) based on berry yield following the criterion suggested by Davee et al.(1986). Thus, plants with berry yield equal to or exceeding 6.25 kg plant^{-1} (3.97 + 2.28) were considered as high-yielding sub population and those below or equal to 1.69 kg plant^{-1} (3.97 - 2.28) were considered as low-yielding sub population. Based on this, there were 201 plants (18 per cent) in the low-yielding group and 185 plants (17 per cent) in the high-yielding group in which the yield pattern of the reference plants followed a normal distribution.

In addition, the whole population was divided into LYG (berry yield < 2.5 kg plant^{-1}), MYG(2.5-5.0 kg plant^{-1}) and HYG (> 5.0 kg plant^{-1}) and each group was subdivided in to low and high yielding sub population using the same criterion adopted as in the general population. This was done to test whether DRIS norms developed by a single general classification will be applicable at all yield levels or yield based sub groups will be required.

3.11.2. Test plants

The test population of 100 plants representing the macro population was sub classified into ten groups (deciles) based on berry yield. The details of decile classification are presented in Tables 15 a, b and c.

3.11.3. Nutrient ratios and DRIS norms

Ratios of every nutrient with all the others were worked out. The possible expression for example, N/P or P/N were worked out. Thus, there were 36 direct and 36 inverse ratios involving 9 elements themselves. This was separately worked out in each sub population and variance ratios were also worked out. The mean value of any expression with the largest variance ratio of the high- yielding sub population constituted the "DRIS norms" (Beaufils, 1973). DRIS norms under the general as well as LYG, MYG and HYG were separately worked out.

3.12. DRIS norms for quality characteristics

DRIS norms for per cent content of oleoresin and yield of oleoresin from a reference population of 1100 vines were also developed following the same procedure adopted for the generation of DRIS norms for yield of berries.

3.13. DRIS Chart

The DRIS norms of three selected nutrients can be related to one another in a so-called DRIS chart, for obtaining qualitative order of requirement of these three nutrients. The point of intersection of the three axes corresponds to the mean value for the high-yielding population for each form of expression. This is the composition desired in order to increase the chances of obtaining a high yield. However, this desired composition should be considered not a single inflexible point but a range encompassed by the inner of the two concentric circles as in Fig. 1 to 8. The diameter of this inner circle is set at 4 SD/3 and the outer circle is set at 8 SD/3 (Beaufils, 1973), where SD is the standard deviation of the high-yielding sub population.

From the selected DRIS norms for yield of berries eight DRIS charts were prepared for qualitative comparison of all possible three nutrient combinations.

3.14. Computation of DRIS indices

DRIS indexing proves a mathematical means of ordering a large number of nutrient ratios and or products into nutrient indices that can be easily interpreted. DRIS indices were calculated using a formula that used the reference ratios or products, their coefficient of variation, and the observed ratios of the sample being evaluated(Walworth and Sumner, 1987). The DRIS norms are used to generate indices by the following equations,

$$\text{N index} = \frac{[-f(P/N)-f(K/N)-f(Ca/N)+f(N/Mg)-f(S/N)+f(N/Fe)-f(Zn/N)-f(Mn/N)]}{8}$$

where, when $P/N \geq p/n$,

$$f(P/N) = \left(\frac{P/N}{p/n} - 1\right)\frac{1000}{CV}$$

or when $P/N < p/n$,

$$f(P/N) = \left(1 - \frac{p/n}{P/N}\right)\frac{1000}{CV}$$

in which P/N is the value of the ratio of the elements P and N in the tissue of the plant (test plant) being diagnosed, p/n is the DRIS norm for that ratio, CV is the coefficient of variation associated with the norm, and 8 is the number of functions comprising the N index.

In the same way, other indices, namely, P K Ca Mg S Fe Zn and Mn indices were worked out.

3.15. Nutritional Imbalance Index (NII)

This was worked out by taking the actual sum of DRIS indices (N index, P index, K index etc.) irrespective of sign. By using the NII, the nutritional imbalance of any desired plant can be obtained. The order of nutrient requirement of any plant can be found out from this, assuming that the most negative DRIS index value represented the most deficient situation and the most positive value represented relatively the most sufficient situation.

RESULTS

4. RESULTS

An investigative analysis of the nutritional relation on the productivity characteristics of black pepper was undertaken at Regional Agricultural Research Station, Ambalavayal during 1993-96. The study included estimation of nutritional characteristics of the rhizosphere, leaf nutrient status as well as expression of yield and quality characteristics. Data generated on various aspects as well as different inter relations helpful in the formulation of a viable diagnostic and recommendation system of nutritional management are presented in the following pages.

4.1 Basic nutritional soil characteristics

Data on the basic rhizosphere soil characteristics generated from a representative micropopulation of 100 test plants are presented in Table 3. It can be seen that the nutritional rhizosphere characteristics showed very wide variation from plant to plant. Every individual rhizosphere almost differed from the other in nutritional soil characteristics. Soil reaction varied between 4.3 and 6.8, organic carbon content between 1.03 and 2.16 percent, the available P content between 3.87 and 26.54 ppm and exchangeable K between 128 and 560 ppm. The corresponding percentage variations worked out to 158, 210, 686 and 438 respectively.

Among the secondary nutrients, the magnitude of variation was highest for sulphur followed by calcium and magnesium in that order and percentage wise variations were of the order of 1127, 919 and 600 respectively.

Table 3 Basic nutritional characteristics of the rhizosphere (n = 100)

Sl. No.	Soil Property	Unit	Mean Value	Range	
				Lower	Upper
1	pH	-	5.62	4.30	6.80
2	Organic carbon	%	1.65	1.03	2.16
3	Available P	ppm	10.14	3.87	25.64
4	Exchangeable K	,,	333.84	128.00	560.00
5	Exchangeable Ca	,,	691.56	144.00	1324.00
6	Exchangeable Mg	,,	90.54	26.00	156.00
7	Available S	,,	52.16	11.70	131.90
8	Available Fe	,,	34.42	19.90	55.90
9	Available Zn	,,	2.44	0.90	4.50
10	Available Mn	,,	60.59	37.00	98.00

The three micro elements studied also showed wide variability in their available status in the rhizosphere. The lowest recorded values of Fe, Mn and Zn in the rhizosphere were 19.9, 37.0 and 0.9 ppm, respectively, and the maximum values were 55.9, 98.0 and 4.5, respectively, and, the magnitude of variation worked out to 281, 265 and 500 per cent, respectively.

These data indicated that the rhizosphere environment of all the experimental plants was in the higher side of soil fertility and no plant had been subjected to absolute deficiency of any major or secondary nutrient.

4.2. Foliar nutrient composition of reference plants

Data on the rate and extent of variation in the leaf nutrient status of the population of pepper plants under study are presented in Table 4. Percentage leaf nitrogen content varied between 1.61 and 2.94, and phosphorus varied between 0.10 and 0.25, while the variation observed for K was between 1.60 and 3.40 percent, and the magnitude of variation was 183, 246, and 213 per cent over the lowest values, respectively. The mean contents of these elements were 2.38, 0.15 and 2.37, respectively.

Among the secondary nutrients, Ca gave the highest mean value of 1.72 per cent followed by S and Mg with 0.208 and 0.207 per cent, respectively. As far as the variability in the leaf content of these elements are concerned, Ca ranged from 1.0 to 2.82, Mg from 0.101 to 0.562 and S from 0.103 to 0.488. The magnitude of variability from the mean were 282, 556 and 474 per cent, respectively.

Among micro elements, Zinc registered the lowest leaf content of 18 ppm and variability was also marginal, the highest content being 43. Lowest Fe and Mn contents were 114 and 200 ppm. Variability in Fe and Mn was high and the

Table 4 Foliar nutrient status of reference plants of black pepper (n = 1100)

Sl. No.	Element	Unit	Mean Value	Range	
				Lower	Upper
1	N	%	2.380	1.610	2.94
2	P	,,	0.156	0.102	0.25
3	K	,,	2.370	1.600	3.40
4	Ca	,,	1.740	1.000	2.82
5	Mg	,,	0.207	0.101	0.56
6	S	,,	0.208	0.103	0.49
7	Fe	ppm	226.000	114.000	808.00
8	Zn	,,	31.000	18.000	43.00
9	Mn	,,	564.000	200.000	990.00

highest values were 808 and 990 ppm, respectively. Extreme variability between units suggested that as far as nutritional characters are considered, each unit appeared to be an independent soil- plant system.

4.3. Inter relationships between nutrient status in soil

Table 5 presents the data on the various inter relationships among nutrients in the rhizosphere. It shall be seen that the soil reaction had manifested significant and positive relationship with exchangeable Ca and Mg contents of the soil and negative relationship with available Fe. Influence of pH on available P was negative though it failed to reach significant levels. The soil pH did not exert any influence on available Zn and Mn.

Available Mn showed significant positive influence on organic carbon, exchangeable Mg and available Zn in the rhizosphere. Zn was positively correlated with the yield of both berries and oleoresin. Influence of Zinc on the soil factors were confined on available P and Fe with the former negative and the latter being positive. Available Fe in the soil was found negatively related to phosphorus and Ca contents in the soil but increased the S content significantly. This indicated an indirect negative relationship of Ca with Zn.

4.4. Yield and quality of berries

Data on the yield of black pepper, percentage oleoresin and oleoresin yield are presented in Table 6. Yield of berries ranged from 0.16 to 13.80 kg plant^{-1}, percentage of oleoresin from 7.0 to 15.5 and oleoresin yield from 0.014 to 1.69 kg plant^{-1}. The variations worked out to 86, 2.2 and 120 fold, respectively.

Table 5 Inter correlation matrix of soil, yield and quality characteristics of test plants of black pepper (n = 100)

	Yield	Or. (%)	Or. yld	Org. C	Av. P	Ex. K	Ex. Ca	Ex. Mg	Av. S	Av. Fe	Av.Zn	Av. Mn
Or. (%)	.108											
Or. yld	.948**	.370**										
Org. C	.245*	- .099	.224*									
Av. P	- .150	- .079	-.178	-.114								
Ex. K	- .067	.107	-.014	-.140	-.121							
Ex. Ca	- .017	.184	.044	-.112	-.056	- .002						
Ex. Mg	.174	.217*	.238*	.099	.003	.124	.481**					
Av. S	.180	.128	.188	.035	.027	.188	- .189	- .050				
Av. Fe	.253*	- .016	.219*	.091	-.221*	.165	- .279**	- .173	.213*			
Av. Zn	.222*	.177*	.278**	.156	-.225*	.093	- .098	.103	.123	.251*		
Av. Mn	.256**	.132	.301**	.300**	.107	- .008	.130	.373**	.082	-.053	.305**	
pH	- .114	.089	-.070	.033	-.154	-. 022	.666**	.313**	- .112	-.188	- .015	.036

* Significance at 5% level. ** Significance at 1% level.
Or = Oleoresin Or.yld = Oleoresin yield

Table 6 Yield and quality characteristics of reference plants of black pepper (n = 1100)

Sl. No.	Character	Unit	Mean Value	Range	
				Lower	Upper
1	Berry yield (Dry)	kg $plant^{-1}$	3.97	0.16	13.80
2	Oleoresin content	%	11.41	7.00	15.50
3	Oleoresin yield	kg $plant^{-1}$	0.46	0.014	1.69

4.5. Inter relations between foliar elemental composition and yield of berries, oleoresin percentage and yield of oleoresin.

Data presented in Table 7 showed that N, Mg and Zn showed significant and positive relation and P, K, S and Mn showed significant but negative relation to yield of both berries and oleoresin.

The data further showed that per cent content of oleoresin was not significantly affected by any of the elements studied other than Fe. Fe significantly increased the oleoresin per cent.

An over all perusal of the data showed that while N, Mg and Zn positively influence the yield of berries; P, K, S and Mn exert negative influence, and elemental effects nullified among themselves. The independent significant influence of Fe on oleoresin percentage, its disappearance and effect of sulphur on oleoresin yield suggest contradictory involvement of these elements in the yield process. This meant net balance interactions are the deciding factors in yield expression.

4.6. Correlation matrix of foliar content of elements with yield and quality characters of different yield group of reference plants

Data in Table 8a revealed that foliar content of elements did not influence yield in LYG, though Mg, S and Mn showed positive but negligible effects. Among applied elements P and K tended to reduce the yield. It appeared that P through its relationship with S tended to increase the yield on the one side and contributed against the same through its effect on Fe. In the same way negative interaction of Ca with Fe and P and positive interaction of Ca with Mn were evident at the LYG which affected the yield indirectly. Phosphorus significantly reduced the oleoresin yield probably through its negative but insignificant relationship with yield. Oleoresin per cent was found significantly and positively affected by foliar content of sulphur.

Table 7 Correlation between leaf nutrient contents and productivity relations of reference plants of black pepper (n = 1100)

Sl. No.	Foliar element	r values		
		Berry yield	Oleoresin content	Oleoresin yield
1	N	0.061*	0.017	0.064*
2	P	- 0.222**	- 0.057	- 0.210**
3	K	- 0.140**	- 0.016	- 0.126**
4	Ca	- 0.004	- 0.045	- 0.019
5	Mg	0.072*	0.044	0.076*
6	S	- 0.079**	0.021	0.076*
7	Fe	- 0.008	0.068*	0.007
8	Zn	0.082**	- 0.024	0.072*
9	Mn	- 0.187**	- 0.043	- 0.180**

* Significant at 5% level
** Significant at 1% level

In the MYG (Table 8b) the direct positive effect of Zn and negative effect of Mn can be found significant. It can also be seen that the influence of Zn is getting suppressed through the negative influence of P and S in this group, while N significantly interacts to boost the effect of Zn. In the same way, the negative effect of Mn is also boosted by P and Ca. The oleoresin per cent was not found to be significantly influenced by any of the elements, but the oleoresin yield was negatively influenced by Mn.

In the HYG, P and S had direct negative effect on yield (Table 8c). The effect of S can be seen to get supplemented by positive influence of P, K and Ca. Mn though did not significantly affect the yield in high yield group manifested positive correlation with K, Ca and S and negative relationship with Zn.

The overall perusal of the data in Tables 8a, b and c showed that in the low yield group, significant relationship of foliar concentration of elements was less apparent and its critical relations become more apparent with progressive increases in yield.

4.7. Correlation between nutrient ratios and yield of berries

It shall be noted from the data in Table 9 that ratios of P with all other elements except Mn, Mn with all but P, and Mg with all except N and Zn significantly affected the yield. A high content of P and Mn and a low content of Mg were reducing the yield. Of these, P is an applied element and so its influence is an applied influence. Mg and Mn are native as they have not been applied elements. Thus the result in short showed that yield process is affected by excess of applied P, excess of native Mn and a deficiency of native Mg. Thus applied excesses and native deficiency and excess have affected the yield.

Table 8. a Inter-correlation matrix of foliar elements, yield and quality characteristics of LYG reference plants of black pepper (n = 307)

	Yield	Or. (%)	Or. yld	N	P	K	Ca	Mg	S	Fe	Zn
Or.(%)	.071										
Or.yld	.926**	.406**									
N	.089	-.102	.053								
P	-.102	-.086	-.129*	-.013							
K	-.029	-.054	-.038	-.053	.250**						
Ca	.087	-.013	.083	.128*	-.049	.012					
Mg	.066	.031	.056	.0002	.078	-.117*	.023				
S	.082	.143*	.110	.053	.250**	.070	.064	.047			
Fe	-.053	.061	-.045	-.011	.149*	.038	-.137*	.097	.099		
Zn	-.0002	-.048	.002	.294**	-.032	.009	.248**	.054	-.086	.076	
Mn	.096	.023	.091	.107	.032	.046	.272**	.090	.068	.081	.041

* Significance at 5% level. ** Significance at 1% level.

Or. = Oleoresin Or.yld = Oleoresin yield

Table 8 b Inter-correlation matrix of foliar elements, yield and quality characteristics of MYG reference plants of black pepper (n = 450)

	Yield	Or. (%)	Or. yld	N	P	K	Ca	Mg	S	Fe	Zn
Or. (%)	.008										
Or.yld	.757**	.647**									
N	.024	.083	.068								
P	-.059	-.053	-.078	-.120*							
K	.002	.026	.015	.016	.266**						
Ca	.005	-.065	-.038	-.015*	.071	-.063					
Mg	.042	.030	.052	-.001	-.093	-.040	.061				
S	-.036	-.028	-.043	-.007	.287**	.109*	.112*	.064			
Fe	.013	.081	.067	.090	.080	-.026	-.017	.097*	.190**		
Zn	.114*	-.041	.066	.317**	-.168**	.016	-.064	.065	-.106*	-.005	
Mn	-.094*	-.058	-.106*	.076	.106*	.099*	.265**	.050	.088	.073	-.096*

* Significance at 5% level. ** Significance at 1% level.

Or. = Oleoresin Or.yld = Oleoresin yield

Table 8 c Inter-correlation matrix of foliar elements, yield and quality characteristics of HYG reference plants of black pepper (n = 343)

	Yield	Or.(%)	Or.yld	N	P	K	Ca	Mg	S	Fe	Zn
Or. (%)	.119*										
Or.yld	.785**	.695**									
N	.071	.030	.060								
P	-.149**	.027	-.085	.092							
K	.001	.015	.017	-.065	.362**						
Ca	.023	-.041	-.015	-.001	-.024	.027					
Mg	.025	.049	.043	-.017	-.071	-.075	.133*				
S	-.182**	-.005	-.135*	.061	.366**	.135*	.021	-.014			
Fe	-.070	.056	-.031	.125*	.090	-.079	-.050	.125*	.118*		
Zn	.068	-.004	.047	.518**	-.120*	-.088	-.079	-.015	-.061	.077	
Mn	.025	-.018	.020	.022	.062	.204**	.385**	.102	.131*	-.016	-.127*

* Significance at 5% level ** Significance at 1% level
Or. = Oleoresin Or.yld = Oleoresin yield

Table 9 Significant correlations between nutrient ratios and yield of berries in black pepper (n = 1100)

Nutrient ratio	r value	Nutrient ratio	r value	Nutrient ratio	r value
N/P	0.213**	K/Zn	- 0.139**	S/Zn	- 0.095**
N/K	0.151**	K/Mn	0.078**	Fe/P	0.076*
N/S	0.081**	Ca/P	0.160*	Fe/Mn	0.080**
N/Fe	0.065*	Ca/K	0.078**	Zn/P	0.205**
N/Mn	0.172**	Ca/Mg	- 0.079**	Zn/K	0.155**
P/N	- 0.224**	Ca/S	0.064*	Zn/Ca	0.072*
P/K	- 0.141**	Ca/Mn	0.134**	Zn/S	0.093**
P/Ca	- 0.166**	Mg/P	0.145**	Zn/Fe	0.081**
P/Mg	- 0.154**	Mg/K	0.101**	Zn/Mn	0.176**
P/S	- 0.073*	Mg/Ca	0.062*	Mn/N	- 0.198**
P/Fe	- 0.889**	Mg/S	0.099**	Mn/K	- 0.116**
P/Zn	- 0.201**	Mg/Fe	0.088**	Mn/Ca	- 0.183**
K/N	- 0.149**	Mg/Mn	0.128**	Mn/Mg	- 0.162**
K/P	- 0.123**	S/N	0.097**	Mn/S	- 0.063*
K/Ca	- 0.078**	S/Ca	- 0.067*	Mn/Fe	- 0.075*
K/Mg	- 0.104**	S/Mg	- 0.095**	Mn/Zn	- 0.181**

* Significant at 5 % level   ** Significant at 1 % level

4.8. DRIS norms for yield of berries in black pepper

DRIS norms were developed by taking the entire population together and also classifying it into LYG, MYG and HYG and then developing the norms separately for each group.

4.8.1. General DRIS norm for yield of berries

Among the nutrient ratios, 36 were selected on the basis of their higher variance ratio and the data for the selected ratios are presented in Table 10, and the data relevant to DRIS norms are given in Appendix II. Only 17 of the 36 nutrient ratios were found to be significantly discriminating between the low-yield and high-yield sub populations. However, to have symmetry of nutrient ratios in the computation of nutrient indices as well as to avoid imbalance in indices, remaining 19 non- significant ratios were also selected. These 36 ratios among themselves included all the elements under study. Results showed that the imbalances of P, S and Mn with other elements were the dominant yield limiting influences.

4.8.2. DRIS norms for yield of berries for LYG, MYG and HYG

The DRIS norms developed for various yield groups are presented in Tables from 11 to 13, and the relevant data in Appendices from III to V. The results indicated the varying influence of nutrient ratios in discriminating between the low and high-yield sub population in all the three yield groups.

The data on the significant effect of different ratios at different yield groups are presented in Table 14. It shall be seen that only 13 ratios significantly influenced the yield of berries in LYG and 16 ratios affected the yield in MYG. As against this, 20 ratios were found to influence the HYG.

Table 10 DRIS norms for yield of berries in black pepper (n = 1100)

Ratio	Low yield group (A)			High yield group (B)			Var.ratio
	Mean	Var.(SA)	CV %	**Mean**	Var. (SB)	CV %	(SA/SB)
N/Mg	15.705	45.602	43.00	**14.967**	49.479	47.00	0.92
N/Fe	117.233	1565.074	33.75	**126.590**	1588.936	31.49	0.98
P/N	0.074	3.480*	25.33	**0.061**	1.900*	22.57	1.84
P/K	0.070	2.530*	22.84	**0.063**	1.640*	20.25	1.54
P/Ca	0.101	9.560*	30.53	**0.086**	5.850*	28.01	1.63
P/Mg	1.133	0.280	46.71	**0.913**	0.227	52.17	1.24
P/S	0.943	0.135	38.94	**0.855**	0.090	35.02	1.50
P/Fe	8.458	9.580	36.60	**7.638**	7.734	36.41	1.24
P/Zn	58.339	304.118	29.89	**48.042**	243.142	32.46	1.25
P/Mn	3.033	1.342	38.19	**2.935**	0.913	32.56	1.47
K/N	1.071	0.039	18.50	**0.976**	0.033	18.49	1.20
K/Ca	1.467	0.108	22.41	**1.375**	0.096	22.55	1.12
K/Mg	16.604	53.097	43.88	**14.585**	53.371	50.09	0.99
K/Fe	123.514	1744.778	33.82	**123.201**	1831.059	34.73	0.95
K/Zn	845.597	39944.078	23.64	**765.112**	40333.570	26.25	0.99
K/Mn	44.131	246.826	35.60	**46.728**	173.029	28.15	1.43
Ca/N	0.753	0.025	21.09	**0.735**	0.027	22.33	0.94
Ca/Mg	11.707	30.275	47.00	**10.738**	26.622	48.05	1.14
Ca/Fe	88.107	1192.974	39.20	**92.871**	1237.216	37.87	0.96
Ca/Zn	593.102	23283.561	25.73	**576.977**	31801.039	30.91	0.73
Mg/Fe	9.425	40.903	67.86	**11.003**	52.693	65.97	0.78
S/N	0.089	0.001	43.10	**0.079**	9.220*	38.42	1.59
S/K	0.084	0.001	43.35	**0.082**	9.950*	38.31	1.34
S/Ca	0.122	0.003	44.91	**0.112**	0.002	42.17	1.34
S/Mg	1.371	0.694	60.77	**1.173**	0.519	61.40	1.34
S/Fe	10.166	25.922	50.08	**9.798**	21.317	47.12	1.22
S/Zn	70.913	1285.196	50.55	**62.417**	877.384	47.46	1.46
Zn/N	0.001	0.000*	18.71	**0.001**	0.000*	14.12	1.73
Zn/Mg	0.020	0.840*	45.37	**0.020**	0.930*	49.27	0.90
Zn/Fe	0.152	0.003	37.96	**0.167**	0.004	35.83	0.92
Mn/N	0.026	0.620*	29.89	**0.022**	0.420*	29.02	1.49
Mn/Ca	0.036	1.000*	28.05	**0.031**	0.630*	25.85	1.58
Mn/Mg	0.405	0.039	48.68	**0.324**	0.028	52.10	1.37
Mn/S	0.345	0.027	47.70	**0.316**	0.019	43.43	1.44
Mn/Fe	3.038	1.649	42.27	**2.797**	1.362	41.72	1.20
Mn/Zn	20.881	52.114	34.57	**17.491**	39.115	35.76	1.33

* x 10^{-4}

Table 11 LYG DRIS norms for yield of berries in black pepper (n = 307)

Ratio	Low yield group (A)			High yield group (B)			Var.ratio
	Mean	Var.(SA)	CV %	Mean	Var.(SB)	CV %	(SA/SB)
N/Ca	1.376	0.104	23.45	**1.357**	0.099	23.18	1.05
N/Mg	16.700	41.793	38.71	**15.515**	44.985	43.23	0.93
N/S	14.027	22.412	33.75	**12.767**	27.154	40.82	0.83
N/Mn	43.521	222.428	34.27	**40.137**	116.740	26.92	1.91
P/N	0.073	3.160*	24.48	**0.067**	3.630*	28.45	0.87
P/K	0.070	2.980*	24.77	**0.066**	2.450*	23.81	1.22
P/Ca	0.099	9.790*	31.61	**0.089**	8.230*	32.16	1.19
P/Mg	1.201	0.291	44.96	**1.015**	0.242	48.50	1.20
P/S	0.988	0.121	35.25	**0.829**	0.142	45.44	0.86
P/Zn	57.014	317.681	31.26	**52.408**	207.061	27.46	1.53
P/Mn	3.091	1.259	36.29	**2.623**	0.783	33.73	1.61
K/N	1.061	0.041	19.14	**1.025**	0.034	17.92	1.22
K/Ca	1.439	0.123	24.41	**1.369**	0.097	22.78	1.27
K/Mg	17.711	57.574	42.84	**15.625**	43.364	42.15	1.33
K/S	14.769	29.825	36.98	**12.803**	25.612	39.53	1.16
K/Zn	830.371	47161.531	26.15	**808.797**	30747.801	21.68	1.53
K/Mn	46.056	347.413	40.47	**40.373**	111.243	26.12	3.12
Ca/Zn	600.179	34577.051	30.98	**610.122**	23092.000	24.91	1.50
Ca/Mn	32.374	115.396	33.18	**30.674**	95.535	31.86	1.21
Mg/Ca	0.105	0.005	67.74	**0.110**	0.004	57.18	1.28
Mg/S	1.072	0.581	71.12	**1.028**	0.529	70.78	1.10
S/Ca	0.110	0.002	44.50	**0.120**	0.002	35.77	1.30
S/Mn	3.490	3.129	50.69	**3.593**	2.353	42.69	1.33
Fe/N	0.010	0.250*	50.02	**0.009**	0.110*	35.62	2.37
Fe/P	0.144	0.006	52.86	**0.143**	0.003	35.54	2.24
Fe/K	0.010	0.270*	53.59	**0.009**	0.110*	36.59	2.49
Fe/Ca	0.014	0.570*	54.66	**0.012**	0.250*	40.04	2.31
Fe/Mg	0.161	0.009	57.47	**0.142**	0.006	56.43	1.35
Fe/S	0.133	0.004	46.12	**0.113**	0.003	47.16	1.33
Fe/Zn	7.747	11.917	44.56	**7.262**	7.283	37.16	1.64
Fe/Mn	0.425	0.051	53.35	**0.360**	0.017	36.14	3.04
Zn/N	0.001	0.000*	19.25	**0.001**	0.000*	18.72	1.09
Zn/Mg	0.022	0.870*	42.72	**0.020**	0.860*	46.46	1.01
Zn/S	0.019	0.530*	39.28	**0.017**	0.580*	45.83	0.92
Zn/Mn	0.057	4.750*	38.05	**0.052**	2.260*	29.10	2.10
Mn/Mg	0.412	0.032	43.56	**0.398**	0.028	42.17	1.15

* $\times 10^{-4}$

Table 12 MYG DRIS norms for yield of berries in black pepper (n = 450)

Ratio	Low yield group (A)			High yield group (B)			Var. ratio
	Mean	Var.(SA)	CV %	Mean	Var.(SB)	CV %	(SA/SB)
N/P	15.987	15.626	24.73	**16.730**	17.583	25.06	0.89
N/Fe	120.051	1670.278	34.04	**121.080**	2021.151	37.13	0.83
N/Zn	836.654	37253.980	23.07	**787.159**	26506.600	20.68	1.41
P/K	0.067	2.390*	22.99	**0.065**	2.070*	22.10	1.16
P/Ca	0.093	5.950*	26.35	**0.090**	7.430*	30.14	0.80
P/Mg	0.979	0.259	51.93	**0.884**	0.186	48.85	1.39
P/Fe	7.872	9.132	38.39	**7.534**	9.171	40.20	1.00
P/Zn	54.986	261.597	29.41	**49.970**	241.734	31.11	1.08
P/Mn	2.980	1.605	42.51	**3.014**	1.143	35.47	1.40
K/N	0.997	0.032	17.85	**0.987**	0.032	18.24	0.98
K/Mg	14.431	44.139	46.04	**14.023**	52.988	51.91	0.83
K/Fe	117.857	1692.785	34.91	**118.005**	1960.353	37.52	0.86
K/Zn	825.219	39339.559	24.04	**773.268**	35932.719	24.51	1.09
Ca/N	0.744	0.039	26.66	**0.729**	0.023	20.60	1.75
Ca/K	0.755	0.036	25.28	**0.760**	0.040	26.16	0.92
Ca/Mg	10.888	32.916	52.70	**10.198**	26.722	50.69	1.23
Ca/Fe	88.863	1403.232	42.15	**88.058**	1332.201	41.45	1.05
Ca/Zn	623.632	47113.328	34.81	**570.794**	22760.820	26.43	2.07
Ca/Mn	33.143	230.777	45.84	**34.150**	92.742	28.20	2.49
Mg/N	0.090	0.003	60.42	**0.093**	0.003	57.45	1.03
Mg/S	1.180	0.771	74.44	**1.166**	0.528	62.34	1.46
Mg/Fe	10.318	45.786	65.58	**11.158**	57.332	67.86	0.80
Mg/Zn	74.636	2254.065	63.61	**72.952**	2053.631	62.12	1.10
S/N	0.089	0.001	42.71	**0.087**	9.570*	35.36	1.51
S/P	1.375	0.344	42.67	**1.423**	0.271	36.55	1.27
S/K	0.090	0.001	41.21	**0.090**	9.620*	34.49	1.44
S/Ca	0.123	0.002	40.60	**0.124**	0.002	38.41	1.09
S/Fe	10.261	25.597	49.31	**10.457**	25.370	48.17	1.01
S/Mn	3.964	4.644	54.36	**4.123**	2.970	41.80	1.56
Fe/Zn	8.248	24.071	59.48	**8.059**	25.650	62.85	0.94
Zn/S	0.016	0.530*	44.02	**0.017**	0.490*	40.99	1.07
Mn/N	0.024	0.600*	31.57	**0.023**	0.360*	26.68	1.65
Mn/K	0.025	0.550*	29.90	**0.023**	0.510*	30.39	1.09
Mn/Mg	0.353	0.035	53.16	**0.316**	0.029	54.22	1.20
Mn/Fe	2.855	1.470	42.47	**2.724**	1.551	45.72	0.95
Mn/Zn	20.693	76.231	42.19	**17.702**	32.857	32.38	2.32

* x 10^{-4}

Table 13 HYG DRIS norms for berry yield in black pepper

Ratio	Low yield group (A)			High yield group (B)			Var.ratio
	Mean	Var. (SA)	CV %	Mean	Var. (SB)	CV %	(SA/SB)
N/Mg	14.440	47.738	47.85	**14.329**	54.871	51.70	0.87
N/Zn	814.437	44341.570	25.86	**761.989**	13024.540	14.98	3.40
N/Mn	49.049	233.600	31.16	**49.950**	343.875	37.13	0.68
P/N	0.065	3.490*	28.93	**0.058**	1.110*	18.29	3.14
P/K	0.067	2.490*	23.45	**0.061**	1.320*	18.88	1.88
P/Ca	0.089	8.240*	32.11	**0.081**	4.300*	25.62	1.91
P/Mg	0.914	0.223	51.68	**0.811**	0.173	51.35	1.29
P/Fe	7.749	8.365	37.33	**7.456**	5.943	32.70	1.41
P/Zn	53.336	487.205	41.38	**44.037**	123.544	25.24	3.94
P/Mn	3.223	2.867	52.55	**2.803**	0.907	33.98	3.16
K/N	0.964	0.031	18.40	**0.970**	0.043	21.45	0.73
K/Mg	13.555	38.239	45.62	**13.515**	47.960	51.24	0.80
K/Fe	117.112	1624.563	34.42	**125.144**	1677.219	32.73	0.97
K/Zn	780.260	52148.000	29.27	**742.003**	41262.250	27.38	1.26
K/Mn	47.077	291.986	36.30	**46.444**	201.740	30.58	1.45
Ca/N	0.753	0.034	24.47	**0.744**	0.032	23.87	1.08
Ca/K	0.798	0.048	27.48	**0.780**	0.029	21.99	1.63
Ca/Zn	607.601	35637.762	31.07	**570.398**	30924.230	30.83	1.15
Ca/Mn	35.618	94.728	27.33	**35.406**	105.055	28.95	0.90
Mg/Ca	0.124	0.006	60.61	**0.133**	0.007	60.71	0.87
Mg/Zn	73.262	2161.765	63.46	**73.764**	2268.874	64.57	0.95
Mg/Mn	4.474	8.723	66.02	**4.536**	7.576	60.68	1.15
S/N	0.094	0.001	36.03	**0.068**	4.420*	31.14	2.59
S/P	1.517	0.322	37.41	**1.186**	0.133	30.74	2.42
S/K	0.100	0.002	41.22	**0.071**	5.310*	32.31	3.17
S/Ca	0.131	0.003	41.68	**0.096**	0.001	39.51	2.10
S/Mg	1.335	0.602	58.08	**0.952**	0.330	60.38	1.82
S/Fe	11.604	34.360	50.52	**8.668**	13.744	42.77	2.50
S/Zn	77.965	1679.466	52.56	**51.836**	445.304	40.71	3.77
S/Mn	4.582	4.244	44.96	**3.267**	1.899	42.18	2.23
Fe/N	0.010	0.320*	58.34	**0.009**	0.160*	46.25	1.97
Fe/Ca	0.013	0.590*	57.98	**0.012**	0.490*	56.59	1.21
Fe/Mg	0.131	0.006	60.87	**0.119**	0.006	62.75	1.14
Fe/Zn	7.805	22.979	61.42	**6.587**	8.650	44.65	2.66
Fe/Mn	0.500	0.266	103.11	**0.431**	0.064	58.67	4.15
Mn/Zn	17.928	41.492	35.93	**17.298**	46.332	39.35	0.90

* $\times 10^{-4}$ CV = Coefficient of variation

Table 14 Significant ratios of LYG, MYG and HYG reference plants of black pepper

LYG (<2.5kg/plant)	MYG (2.5 - 5.0 kg/ plant)	HYG (>5.0 kg/ plant)
N/Mn	N/Ca	N/P
P/Zn	N/S	N/Zn
P/Mn	N/Zn	P/N
K/Fe	P/Mg	P/K
K/Zn	P/Mn	P/Ca
K/Mn	Ca/N	P/Zn
Fe/N	Ca/Zn	P/Mn
Fe/P	Ca/Mn	S/N
Fe/K	Mg/S	S/P
Fe/Ca	S/N	S/K
Fe/Zn	S/K	S/Ca
Fe/Mn	S/Mn	S/Mg
Zn/Mn	Zn/Ca	S/Fe
	Mn/N	S/Zn
	Mn/S	S/Mn
	Mn/Zn	Fe/N
		Fe/Zn
		Fe/Mn
		Zn/N
		Zn/P

A further perusal of the data will show that in the LYG, the imbalance of elements in relation to Fe was the dominant yield limiting factor. As Fe is not applied and being a native factor, it shall be termed as native inhibitor to productivity. The influences of Ca, S and Mn ratios were dominant yield limiters in MYG. In the case of HYG the yield limiting influence of S, P and Fe was significant.

4.9. Diagnosis of nutrient imbalance in test plants

An attempt was made to investigate the nutrient imbalance in a test population of 100 plants in respect of yield using the DRIS norms already developed. For this purpose, the 100 test plants were grouped into deciles comprising of 10 classes on the basis of the berry yield so as to facilitate an effective comparison of nutritional imbalance.

The data pertaining to leaf nutrients, their index values with general norms as well as with group norms and the order of requirement of nutrients of decile yield classes are presented in Tables 15a to 15g.

The data showed that a classification of the experimental population into decile groups and application of either general or group norms gave better results than singular designation as LYG, MYG or HYG. It appeared as good as working out DRIS norms at different levels. These results suggested that grouping criteria for development of norms has not much significance.

A further perusal of the data has thrown insight into the yield process of pepper. Upto an yield level of 3.77 kg plant^{-1} (Low Yield Group) Zn had been in all the deciles the most limiting element and the least required was P. In the mid yield group, Zn, N and K were limiting, whereas in the high yield groups Ca and Mg were limiting and the least required was the Fe which is related to quality.

TABLE 15. a **Foliar nutrient status of the test plants of black pepper in relation to yield of berries (n = 100)**

Sl. No	Yield Class (Deciles) kg $plant^{-1}$	N	P	K	Ca	Mg	S	Fe	Zn	Mn	Mean yield of berries(kg $plant^{-1}$)
		Percent						ppm			
1	<1.12	2.35	0.173	2.47	1.66	0.187	0.185	220	29	636	0.795
2	1.12 – 1.88	2.12	0.203	2.31	1.73	0.161	0.215	246	26	715	1.466
3	1.88 – 2.57	2.30	0.173	2.26	1.75	0.171	0.190	225	28	577	2.180
4	2.57 – 3.21	2.45	0.175	2.43	1.86	0.212	0.196	195	31	571	2.731
5	3.21 – 3.77	2.39	0.174	2.45	1.96	0.227	0.213	198	30	635	3.535
6	3.77 – 4.49	2.20	0.158	2.40	1.80	0.176	0.183	246	29	617	4.074
7	4.49 – 5.14	2.49	0.159	2.24	1.79	0.228	0.221	222	30	528	4.725
8	5.14 – 5.84	2.52	0.165	2.38	1.66	0.171	0.211	204	31	544	5.443
9	5.84 – 7.00	2.33	0.153	2.54	1.82	0.112	0.251	256	33	515	6.508
10	> 7.00	2.51	0.145	2.31	1.68	0.168	0.189	229	31	589	8.222

Table 15. b DRIS INDICES of test plants of black pepper in relation to yield of berries (n = 100)

Sl. no.	Yield class (deciles). kg/plant	Nutrient indices									NII	Mean yield (kg/plant)
		N	P	K	Ca	Mg	S	Fe	Zn	Mn		
1.	<1.12	-3	4	-1	-4	2	-2	3	-4	5	28	0.795
2.	1.12-1.88	-9	11	-5	-3	-2	2	7	-10	9	58	1.466
3.	1.88-2.57	-3	5	-3	-1	0	0	5	-5	2	24	2.180
4.	2.57-3.21	-2	4	-2	0	4	-1	-1	-2	0	16	2.731
5.	3.21-3.77	-4	2	-3	1	5	1	-1	-4	3	24	3.535
6.	3.77-4.49	-6	1	-1	0	0	-2	8	-4	4	26	4.074
7.	4.49-5.14	0	0	-5	-1	6	3	3	-4	-2	24	4.725
8.	5.14-5.84	1	2	-2	-3	0	2	2	-2	0	14	5.443
9.	5.84-7.00	-4	-1	1	0	-12	8	10	1	-3	40	6.508
10.	>7.00	1	-3	-2	-3	0	0	5	-1	3	18	8.222

Table 15.c Comparison of DRIS and critical level approaches for diagnosing nutrient imbalance of test plants in relation to yield of berries in black pepper

Sl. No	Yield Class (Deciles) kg plant^{-1}	Order of nutrient requirement.	Mean yield (kg plant^{-1})	Deficient nutrients identified using critical values of De Waard (1969)	Nybe (1986)
1	<1.12	Zn = Ca > N > S > K > Mg > Fe > P > Mn	0.795	N, Mg	P, Ca, Mg, Zn
2	1.12 – 1.88	Zn > N > K > Ca > Mg > S > Fe > Mn > P	1.466	N, Mg	P, Ca, Mg, Zn
3	1.88 – 2.57	Zn > N = K > Ca > Mg = S > Mn > Fe = P	2.180	N, Mg	P, Ca, Mg, Zn
4	2.57 – 3.21	Zn = N = K > S = Fe > Ca = Mn > Mg = P	2.731	N	P, Ca, Mg
5	3.21 – 3.77	Zn = N > K > Fe > Ca = S > P > Mn > Mg	3.535	N	P, Ca, Mg
6	3.77 – 4.49	N > Zn > S > K > Ca = Mg > P > Mn > Fe	4.074	N, Mg	P, Ca, Mg, Zn
7	4.49 – 5.14	K > Zn > Mn > Ca > N = P > S = Fe > Mg	4.725	N	P, Ca, Mg, Zn
8	5.14 – 5.84	Ca > Zn = K > Mg = Mn > N > P = S = Fe	5.443	N, Mg	P, Ca, Mg
9	5.84 – 7.00	Mg > N > Mn > P > Ca > K = Zn > S > Fe	6.508	N, Mg	P, Ca, Mg
10	> 7.00	P = Ca > K > Zn > Mg = S > N > Mn > Fe	8.222	N, Mg	P, Ca, Mg

Table 15 d. DRIS indices of test plants of black pepper with LYG, MYG and HYG norms in relation to yield of berries

Sl. no	Yield class (deciles) kg/plant	Nutrient indices N	P	K	Ca	Mg	S	Fe	Zn	Mn	NII	Mean Yield kg/plant
	Low yield class with LYG norms											
1.	< 1.12	-1	3	0	-3	3	-1	-1	-2	2	16	0.795
2.	1.12-1.88	-6	9	-4	-1	-1	2	2	-8	7	40	1.466
3.	1.88-2.57	-1	3	-2	1	2	0	1	-3	-1	14	2.180
	Medium yield class with MYG norms											
4.	2.57-3.21	-1	4	-1	0	1	-3	-1	0	1	12	2.731
5.	3.21-3.77	-3	2	-1	1	2	-1	-2	-2	4	18	3.535
6.	3.77-4.49	-4	1	1	0	-2	-4	5	-2	5	24	4.074
7.	4.49-5.14	1	0	-3	0	3	1	2	-2	-2	14	4.725
	High yield class with HYG norms											
8.	5.14-5.84	0	4	-2	-4	-3	6	-1	-2	2	24	5.443
9.	5.84-7.00	-5	1	1	0	-16	13	5	1	0	42	6.508
10.	> 7.00	0	-1	-2	-3	-3	3	2	-1	5	20	8.222

Table 15. e Comparison of DRIS and critical level approaches for diagnosing nutrient imbalance of various yield groups of test plants of black pepper in relation to yield of berries

Sl. No.	Yield class (deciles) kg/plant	Order of nutrient requirement	Mean Yield kg/plant	Deficient nutrients identified using critical values of De Waard (1969)	Nybe (1986)
	Low yield class with LYG norms				
1.	< 1.12	Ca > Zn > N = S = Fe > K > Mn > Mg = P	0.795	N, Mg	P, Ca, Mg, Zn
2.	1.12 - 1.88	Zn > N > K > Ca = Mg > S = Fe > Mn > P	1.466	N, Mg	P, Ca, Mg, Zn
3.	1.88 - 2 .57	Zn > K > N = Mn > S > Ca = Fe > Mg > P	2.180	N, Mg	P, Ca, Mg , Zn
	Medium yield class with MYG norms				
4.	2.57 - 3.21	S > K > N = Fe > Ca = Zn > Mg = Mn > P	2.731	N	P, Ca, Mg
5.	3.21 - 3.77	N > Zn = Fe > K = S > Ca > P = Mg > Mn	3.535	N	P, Ca, Mg
6.	3.77 - 4.49	N = S > Zn = Mg > Ca > P = K > Fe = Mn	4.074	N, Mg	P, Ca, Mg, , Zn
7.	4.49 - 5.14	K > Zn = Mn > Ca = P > N = S > Fe > Mg	4.725	N	P, Ca, Mg, Zn
	High yield class with HYG norms				
8.	5.14 - 5.84	Ca > Mg > K = Zn > Fe > N > Mn > P > S	5.443	N, Mg	P, Ca, Mg
9.	5.84 - 7.00	Mg > N > Ca = Mn > P = K = Zn > Fe > S	6.508	N, Mg	P, Ca, Mg
10.	> 7.00	Mg = Ca > K > P = Zn > N > Fe > S > Mn	8.222	N, Mg	P, Ca, Mg

Table 15 f DRIS indices and nutrient imbalance with HYG norms on test plants black pepper in relation to yield of berries

Sl. No	Yield class (deciles) kg/plant	N	P	K	Ca	Mg	S	Fe	Zn	Mn	NII	Mean Yield kg/plant
		Nutrient indices										
1.	< 1.12	-4	7	-1	-5	-2	1	1	-4	7	32	0.795
2.	1.12-1.88	-11	16	-5	-4	-6	6	3	-10	11	72	1.466
3.	1.88-2.57	-4	9	-4	-1	-3	3	2	-6	4	36	2.180
4.	2.57-3.21	-4	6	-2	-1	1	3	-3	-2	2	24	2.731
5.	3.21-3.77	-5	5	-3	1	2	4	-4	-5	5	34	3.535
6.	3.77-4.49	-7	3	-1	-1	-3	1	4	-4	6	30	4.074
7.	4.49-5.14	-2	2	-5	-1	2	7	1	-4	0	24	4.725
8.	5.14-5.84	0	4	-2	-4	-3	6	-1	-2	2	24	5.443
9.	5.84-7.00	-5	1	1	0	-16	13	5	1	0	42	6.508
10.	> 7.00	0	-1	-2	-3	-3	3	2	-1	5	20	8.222

Nutrient Imbalance

Sl. No.	Yield class (deciles) kg/plant	Order of nutrient requirement	Mean Yield kg/plant
1.	< 1.12	Ca > Zn = N > Mg > K > S = Fe > P = Mn	0.795
2.	1.12-1.88	N > Zn > Mg > K > Ca > Fe > S > Mn > P	1.466
3.	1.88-2.57	Zn > N = K > Mg > Ca > Fe > S > Mn > P	2.180
4.	2.57-3.21	N > Fe > Zn = K > Ca > Mg > Mn > S > P	2.731
5.	3.21-3.77	N = Zn > Fe > K > Ca > Mg > S > Mn > P	3.535
6.	3.77-4.49	N > Zn > Mg > K = Ca > S > P > Fe > Mn	4.074
7.	4.49-5.14	K > Zn > N > Ca > Mn > Fe > Mg = P > S	4.725
8.	5.14-5.84	Ca > Mg > K = Zn > Fe > N > Mn > P > S	5.443
9.	5.84-7.00	Mg > N > Ca = Mn > P = K = Zn > Fe > S	6.508
10.	> 7.00	Mg = Ca > K > P = Zn > N > Fe > S > Mn	8.222

Table 15.g   **Nutrient imbalance of test plants of black pepper with general norms in relation to yield of berries**

Sl. no.	Yield class (deciles) kg/plant	Leaf composition N	P	K	Ca	Mg	S	Fe	Zn	Mn	Mean yield kg/plant
		Percent						ppm			
1	n= 10 class	2.37	0.17	2.38	1.77	0.181	0.205	224	30	593	3.97
2	n= 3 (LYG)	2.26	0.18	2.35	1.71	0.173	0.197	230	28	643	1.48
3	n= 4 (MYG)	2.38	0.17	2.38	1.85	0.211	0.203	215	30	588	3.77
4	n= 3 (HYG)	2.45	0.15	2.41	1.72	0.150	0.217	230	32	549	6.72

Sl. no.	Yield class (deciles) kg/plant	Nutrient indices N	P	K	Ca	Mg	S	Fe	Zn	Mn	NII	Mean yield kg/plant
1	n= 10 class	- 3	2	-2	-2	1	1	4	-3	2	20	3.97
2	n= 3 (LYG)	- 5	7	-3	-3	0	0	5	-6	5	34	1.48
3	n= 4 (MYG)	- 3	2	-3	0	4	1	2	-4	1	20	3.77
4	n= 3 (HYG)	- 1	- 1	-1	-2	-3	3	5	0	0	16	6.72

Sl. no.	Yield class (deciles) kg/plant	Order of requirement	NII	Mean yield kg/plant
1	n= 10 class	Zn > N > K = Ca > Mg = S > Mn = P > Fe	20	3.97
2	n= 3 (LYG)	Zn > N > K = Ca > Mg = S > Fe = Mn > P	34	1.48
3	n= 4 (MYG)	Zn > N = K > Ca > S = Mn > P > Fe > Mg	20	3.77
4	n= 3 (HYG)	Mg > Ca > K = N = P > Zn = Mn > S > Fe	16	6.72

P has been found to be limiting only in the higher yield class yielding beyond 7 kg plant^{-1}. The yield process appeared to take a shift at 3.77 kg plant^{-1}. Beyond 5 kg, yield and oleoresin per cent increases may be under inverse relations.

4.10. DRIS norms for per cent content of oleoresin

Data on the DRIS norms for per cent content of oleoresin presented in Table 16 and Appendix VI showed that of the 36 ratios only two were found to discriminate significantly between low and high percentage oleoresin contents, and they were Ca/N and S/Mg. This narrowed - down nutritional influence possibly points out to the fact that qualitative development of berries is largely independent of quantitative yield process.

4.11. DRIS norms for yield of oleoresin

Data presented in Table 17 and Appendix VII on the 36 ratios with high variance ratio, 16 were found to significantly discriminate between the low and high oleoresin yield groups. As in the case of yield of berries, here again contents of elements relative to P, S and Mn were found to limit the yield of oleoresin. The results showed that content of P relative to N, K, Fe and content of S relative to N, P, K, Ca, Mg and Zn, and excess content of Mn in relation to N, Ca, S stand in the way of higher oleoresin yield.

4.12. Influence of nutritional factors on DRIS indices

Table 18 a and b present the variation in the order of limiting influence of elements when the factors considered are different. When NPK alone were taken Nutritional Imbalance Index (NII) was 14 and limiting factor was N, as against N and Ca were limiting nutrient elements and NII was 16 for the same decile class when five factors considered. These showed that order of limiting influences and NII are not absolute but are only relative indices.

Table 16 DRIS norms for percent content oleoresin in black pepper (n = 1100)

Ratio	Low yield group (A)			High yield group (B)			Var.ratio
	Mean	Var. (SA)	CV %	Mean	Var. (SB)	CV %	(SA/SB)
N/K	0.999	0.031	17.58	**1.024**	0.035	18.17	0.89
N/Fe	128.317	1398.956	29.15	**121.429**	1643.662	33.39	0.85
P/N	0.069	2.710*	23.97	**0.065**	2.650*	24.96	1.02
P/K	0.067	2.180*	21.96	**0.065**	2.100*	22.16	1.04
P/Mg	1.026	0.258	49.57	**0.945**	0.222	49.84	1.17
P/S	0.892	0.130	40.50	**0.850**	0.106	38.35	1.23
P/Fe	8.708	9.014	34.48	**7.822**	8.435	37.13	1.07
P/Zn	54.568	230.998	27.85	**52.101**	275.902	31.88	0.84
P/Mn	2.977	1.410	39.88	**2.986**	1.226	37.09	1.15
K/Mg	15.255	44.532	43.75	**14.585**	46.387	46.70	0.96
K/S	13.627	30.246	40.36	**13.419**	28.315	39.66	1.07
K/Fe	131.047	1562.826	30.17	**121.143**	1750.870	34.54	0.89
K/Zn	820.809	35566.219	22.98	**802.630**	40700.699	25.14	0.87
K/Mn	44.571	235.487	34.43	**45.911**	194.932	30.41	1.21
Ca/N	0.777	0.035	24.18	**0.732**	0.028	22.66	1.28
Ca/P	11.754	10.940	28.14	**11.752**	11.571	28.95	0.95
Ca/K	0.762	0.030	22.75	**0.743**	0.038	26.18	0.80
Ca/Mg	11.382	27.049	45.69	**10.555**	27.250	49.46	0.99
Ca/S	10.086	15.751	39.35	**9.786**	18.146	43.53	0.87
Ca/Fe	98.771	1187.415	34.89	**87.896**	1040.139	36.69	1.14
Ca/Zn	620.638	35053.172	30.17	**584.704**	31972.529	30.58	1.10
Mg/N	0.087	0.003	61.01	**0.090**	0.003	57.58	1.05
Mg/Fe	10.580	37.430	57.83	**10.729**	51.161	66.67	0.73
Mg/Mn	3.758	7.574	73.24	**4.054**	6.188	61.36	1.22
S/N	0.088	0.001	42.75	**0.087**	0.001	41.03	1.13
S/Mg	1.312	0.697	63.61	**1.231**	0.519	58.51	1.34
S/Fe	10.953	24.400	45.10	**10.368**	28.677	51.65	0.85
Zn/N	0.001	0.000*	15.61	**0.001**	0.000*	17.29	0.80
Zn/Mg	0.020	0.860*	47.66	**0.019**	0.810*	47.89	1.06
Zn/S	0.017	0.540*	42.80	**0.018**	0.580*	43.37	0.94
Zn/Fe	0.165	0.003	33.63	**0.157**	0.004	37.89	0.87
Mn/N	0.025	0.620*	31.32	**0.024**	0.500*	29.96	1.24
Mn/Ca	0.033	1.010*	30.36	**0.033**	0.930*	29.26	1.09
Mn/S	0.329	0.025	48.28	**0.314**	0.023	48.16	1.11
Mn/Fe	3.158	1.443	38.03	**2.825**	1.463	42.82	0.99
Mn/Zn	20.137	55.029	36.84	**18.807**	45.718	35.95	1.20

* x 10^{-4}

Table 17 DRIS norms for yield of oleoresin in black pepper (n = 1100)

Ratio	Low yield group (A)			High yield group (B)			Var.ratio
	Mean	Var.(SA)	CV %	Mean	Var.(SB)	CV %	(SA/SB)
N/Ca	1.404	0.100	22.56	**1.406**	0.089	21.26	1.12
N/Mg	15.838	43.616	41.70	**14.826**	47.050	46.26	0.93
N/Fe	118.315	1558.876	33.37	**122.470**	1682.871	33.50	0.93
P/N	0.074	3.480*	25.29	**0.062**	1.770*	21.57	1.97
P/K	0.070	2.640*	23.24	**0.064**	1.790*	20.88	1.47
P/Ca	0.103	0.001	31.34	**0.086**	6.930*	30.42	1.49
P/Mg	1.147	0.280	46.11	**0.918**	0.222	51.33	1.26
P/Fe	8.566	9.945	36.82	**7.455**	7.529	36.81	1.32
P/Zn	58.458	314.321	30.33	**49.374**	257.459	32.50	1.22
K/N	1.070	0.039	18.46	**0.978**	0.033	18.56	1.18
K/Ca	1.479	0.114	22.84	**1.358**	0.093	22.45	1.23
K/Mg	16.817	53.650	43.56	**14.413**	48.915	48.53	1.10
K/Fe	124.840	1808.718	34.07	**119.083**	1836.319	35.99	0.98
K/Zn	845.030	41403.672	24.08	**779.686**	45439.219	27.34	0.91
K/Mn	44.975	267.721	36.38	**47.331**	186.875	28.88	1.43
Ca/Mg	11.747	29.604	46.32	**10.743**	25.582	47.08	1.16
Ca/Fe	88.205	1185.971	39.04	**90.382**	1168.920	37.83	1.01
S/N	0.088	0.001	42.16	**0.077**	8.230*	37.23	1.67
S/P	1.224	0.259	41.59	**1.266**	0.178	33.29	1.46
S/K	0.084	0.001	42.30	**0.080**	8.780*	36.90	1.43
S/Ca	0.122	0.003	45.38	**0.108**	0.002	42.46	1.45
S/Mg	1.369	0.635	58.21	**1.142**	0.484	60.93	1.31
S/Fe	10.088	22.532	47.06	**9.271**	20.057	48.31	1.12
S/Zn	70.367	1257.274	50.39	**62.120**	886.794	47.94	1.42
Fe/Mg	0.148	0.006	54.04	**0.138**	0.008	64.04	0.83
Zn/N	0.001	0.000*	18.74	**0.001**	0.000*	15.28	1.53
Zn/Ca	0.002	0.000*	24.48	**0.002**	0.000*	27.57	0.77
Zn/Mg	0.021	0.850*	44.91	**0.019**	0.840*	47.97	1.01
Zn/Fe	0.153	0.003	37.58	**0.159**	0.004	37.87	0.91
Mn/N	0.026	0.600*	29.82	**0.022**	0.390*	28.55	1.51
Mn/P	0.369	0.019	36.96	**0.368**	0.014	32.08	1.33
Mn/Ca	0.035	1.050*	28.96	**0.030**	0.660*	27.03	1.58
Mn/Mg	0.399	0.035	46.65	**0.318**	0.028	52.12	1.26
Mn/S	0.340	0.026	47.80	**0.319**	0.019	43.25	1.39
Mn/Fe	2.993	1.488	40.76	**2.684**	1.395	44.01	1.06
Mn/Zn	20.487	48.656	34.05	**17.603**	40.493	36.15	1.20

* x 10^{-4}

Table 18 a Influence of nutritional factors (N P K) on NII of test plants in relation to yield of berries

SL. No.	Yield class (deciles) kg/plant	N	P	K	DRIS indices			NII	Order of requirement	Mean yield (kg/plant)
		Per cent			N	P	K			
1.	< 1.12	2.35	0.173	2.47	-6	7	-1	14	N > K > P	0.795
2.	1.12 - 1.88	2.12	0.203	2.31	-16	22	6	44	N > K > P	1.466
3.	1.88 - 2.57	2.30	0.173	2.26	-5	10	-5	20	N = K > P	2.180
4.	2.57 - 3.21	2.45	0.175	2.43	-4	7	-3	14	N > K > P	2.731
5.	3.21 - 3.77	2.39	0.174	2.45	-5	7	-2	14	N > K > P	3.535
6.	3.77 - 4.49	2.20	0.158	2.40	-7	5	2	14	N > K > P	4.074
7.	4.49 - 5.14	2.49	0.159	2.24	1	4	-5	10	K > N > P	4.725
8.	5.14 - 5.84	2.52	0.165	2.38	-1	4	-3	8	K > N > P	5.443
9.	5.84 - 7.00	2.33	0.153	2.54	-5	1	4	10	N > P > K	6.508
10.	> 7.00	2.51	0.145	2.31	3	-2	-1	6	P > K > N	8.222

Table 18. b Influence of nutritional factors (N P K Ca Mg) on NII of test plants in relation to yield of berries

SL. No.	Yield class (deciles) kg/plant	N	P	K	Ca	Mg	DRIS indices N	P	K	Ca	Mg	NII	Order of requirement	Mean yield (kg/plant)
		Per cent												
1.	< 1.12	2.35	0.173	2.47	1.66	0.19	-4	5	0	-4	3	16	N = Ca > K > Mg > P	0.795
2.	1.12 - 1.88	2.12	0.203	2.31	1.73	0.16	-9	16	-4	-2	-1	32	N > K > Ca > Mg > P	1.466
3.	1.88 - 2.57	2.30	0.173	2.26	1.75	0.17	-4	7	-4	0	1	16	N = K > Ca > Mg > P	2.180
4.	2.57 - 3.21	2.45	0.175	2.43	1.86	0.21	-4	4	-4	-1	5	18	N = K > Ca > P > Mg	2.731
5.	3.21 - 3.77	2.39	0.174	2.45	1.96	0.23	-6	3	-4	1	6	20	N > K > Ca > P > Mg	3.535
6.	3.77 - 4.49	2.20	0.158	2.40	1.80	0.18	-6	3	0	1	2	12	N > K > Ca > Mg > P	4.074
7.	4.49 - 5.14	2.49	0.159	2.24	1.79	0.23	-1	1	-6	-1	7	16	K > N = Ca > P > Mg	4.725
8.	5.14 - 5.84	2.52	0.165	2.38	1.66	0.17	1	4	-2	-4	1	12	Ca > K > N = Mg > P	5.443
9.	5.84 - 7.00	2.33	0.153	2.54	1.82	0.11	-1	2	5	4	-10	22	Mg > N > P > Ca > K	6.508
10.	> 7.00	2.51	0.145	2.31	1.68	0.17	3	-1	-1	-2	1	8	Ca > P = K > Mg > N	8.222

Table 19 Effect of leaf position (number) on the nutrient requirements identified by DRIS in black pepper using data published by Sushama (1982)

Sl. No.	Leaf position/number	Leaf composition(%)			DRIS indices			Method of diagnosis	
		N	P	K	N	P	K	Order of requirement by DRIS	Critical Value *De Waard (1969)
1.	First older mature leaf	3.51	0.145	1.84	34	-5	-29	K > P > N	K
2.	Second older mature leaf	3.33	0.134	1.63	38	-4	-34	K > P > N	K
3.	Third older mature leaf	3.21	0.116	1.36	51	-7	-44	K > P > N	K
4.	Fourth older mature leaf	2.69	0.116	1.36	34	-1	-33	K > P > N	K

* **Critical values (De Waard, 1969) N = 2.7%, P = 0.10%, K = 2.00%.**

Table 20 **Effect of period of sampling/leaf age on the nutrient requirements identified by DRIS in black pepper using data published by Sushama (1982) and Nybe(1986)**

Sl. No.	Leaf position/number	Leaf composition(%)			DRIS indices			Method of diagnosis	
		N	P	K	N	P	K	Order of requirement by DRIS	Critical Value *De Waard (1969)
	Sushama (1982)								
1.	After the harvest of berries	3.26	0.119	1.44	47	-7	-40	K > P > N	K
2.	Prior to flushing	3.86	0.116	1.46	66	-17	-49	K > P > N	K
3.	One month after flushing	3.23	0.160	1.44	37	14	-51	K > P > N	K
4.	Two months after flushing	2.67	0.182	1.77	10	18	-28	K > N > P	K
5.	Three months after flushing	3.53	0.144	1.84	34	-5	-29	K > P > N	K
6.	Four months after flushing	3.37	0.209	1.50	32	30	-62	K > P > N	K
7.	Five months after flushing	2.60	0.207	1.42	15	39	-54	K > N > P	K
8.	Six months after flushing	2.86	0.165	1.23	36	26	-62	K > P > N	K
9.	Seven months after flushing	2.72	0.198	1.26	26	41	-67	K > N > P	K
	Nybe (1986)								
1.	April, 1981	2.23	0.160	1.33	13	26	-39	K > P > N	K
2.	June, 1981	2.71	0.210	1.56	13	34	-47	K > P > N	K
3.	August, 1981	2.46	0.200	1.03	29	58	-87	K > P > N	K
4.	October, 1981	2.62	0.180	1.57	14	23	-37	K > P > N	K
5.	December, 1981	2.27	0.170	1.39	11	28	-39	K > P > N	K

Table 21 Relevant data for the construction of DRIS chart

Sl. No.	Nutrient Combination	Ratio	DRIS norm	4 SD/3	8 SD/3
1	N-P-S	P/N	0.0610	0.0184	0.0367
		P/S	0.8551	0.3993	0.7985
		S/N	0.0790	0.0405	0.0810
2	N-P-Mn	P/N	0.0610	0.0184	0.0367
		P/Mn	2.9351	1.2741	2.5483
		Mn/N	0.0222	0.0086	0.0172
3	N-S-Zn	S/N	0.0790	0.0405	0.0810
		S/Zn	62.4171	39.4942	78.9884
		Zn/N	0.0013	0.0002	0.0005
4	N-S-Mn	S/N	0.0790	0.0405	0.0810
		Mn/S	0.3158	0.1829	0.3657
		Mn/N	0.0222	0.0086	0.0172
5	N-Zn-Mn	Zn/N	0.0013	0.0002	0.0005
		Mn/Zn	17.4908	8.3389	16.6779
		Mn/N	0.0222	0.0086	0.0172
6	P-K-S	P/K	0.0633	0.0171	0.0342
		S/K	0.0823	0.0421	0.0841
		P/S	0.8551	0.3993	0.7985
7	P-K-Mn	P/K	0.0633	0.0171	0.0342
		K/Mn	46.7275	17.5387	35.0775
		P/Mn	2.9351	1.2741	2.5483
8	Mg-S-Mn	S/Mg	1.1732	0.9605	1.9210
		Mn/S	0.3158	0.1829	0.3657
		Mn/Mg	0.3236	0.2248	0.4495

4.13. DRIS approach and sampling for foliar elements

The accuracy of nutritional diagnosis by DRIS is reported to be less influenced by leaf position/number and age of plant or period of sampling, as nutrient ratios were frequently less affected by plant age than nutrient concentrations based on dry matter.

The data presented in Table 19 and 20 showed that the order of requirement of nutrients remained unchanged though wide variation in concentration was observed in respect of individual nutrients either due to leaf maturity or period of sampling, when diagnosis was made by DRIS approach. Thus DRIS offers flexibility of sampling of foliar tissue irrespective of maturity or index leaf as important in other diagnostic methods.

4.14. DRIS Chart

DRIS charts are the graphical representation of the qualitative relationship of maximum of three nutrients each. Table 21 presents the possible three nutrient relationship of significant nutrient ratios discriminating the low and high yield sub population in respect of yield of berries. Eight such DRIS charts are presented from Fig. 1 to 8.

It may be noted that as the yield expression is influenced by the relative deficiencies or excesses of a number of nutritional factors, the very same presentation as DRIS charts permitting only three nutrients, limits the better understanding of the most limiting elements in the diagnosis.

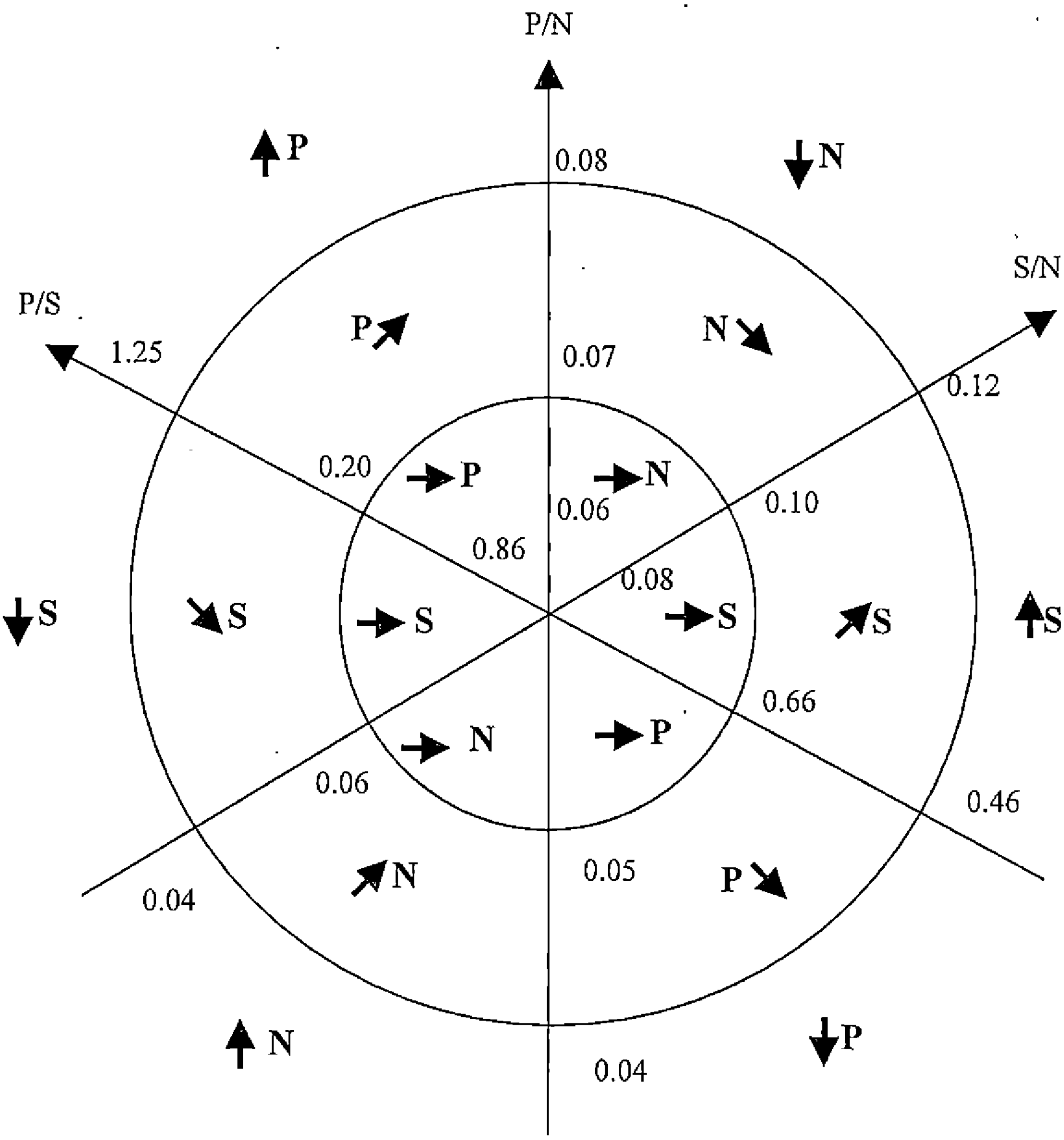

Fig.1 DRIS chart involving N, P and S for berry yield in black pepper

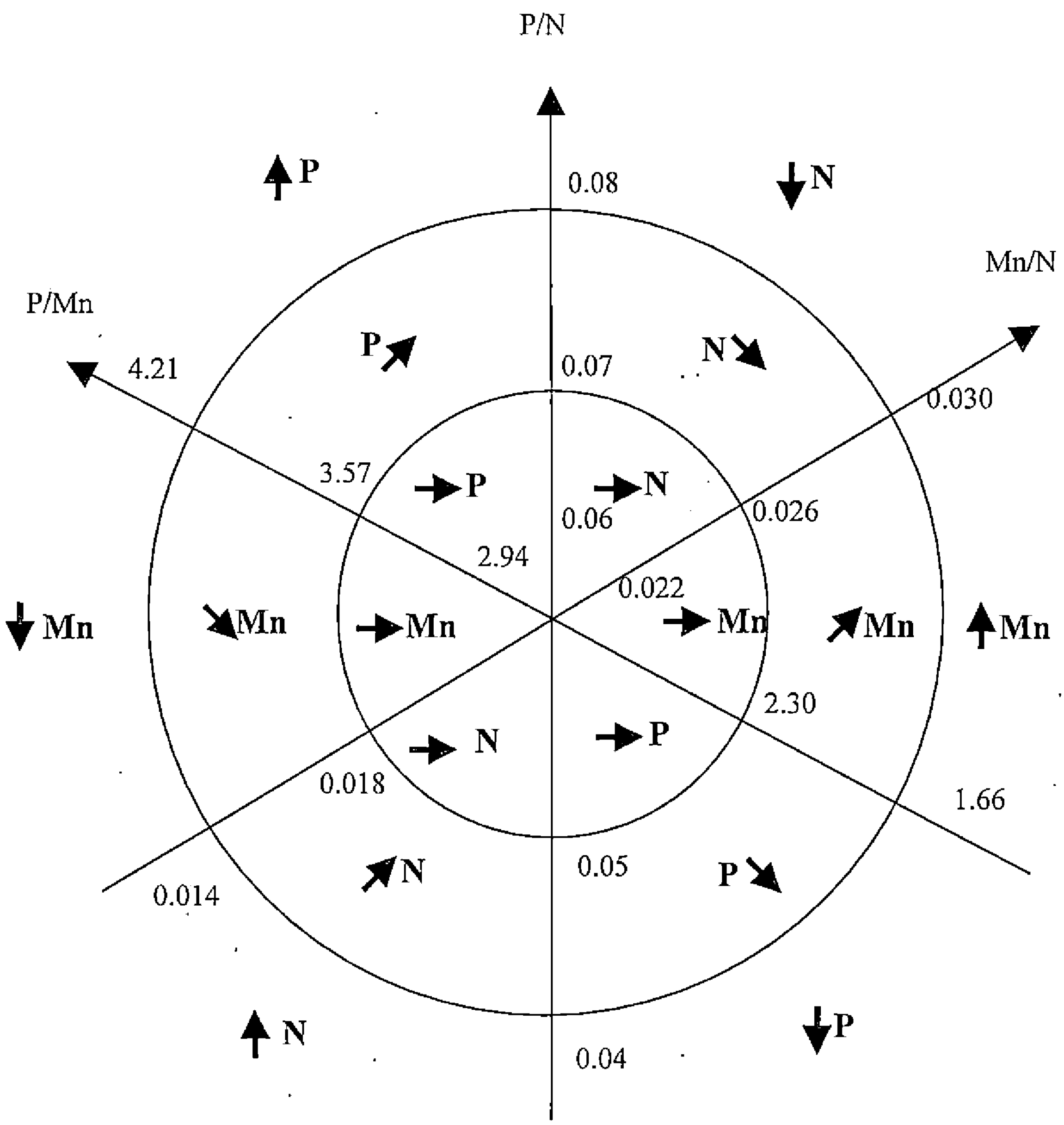

Fig.2 DRIS chart involving N, P and Mn for berry yield in black pepper

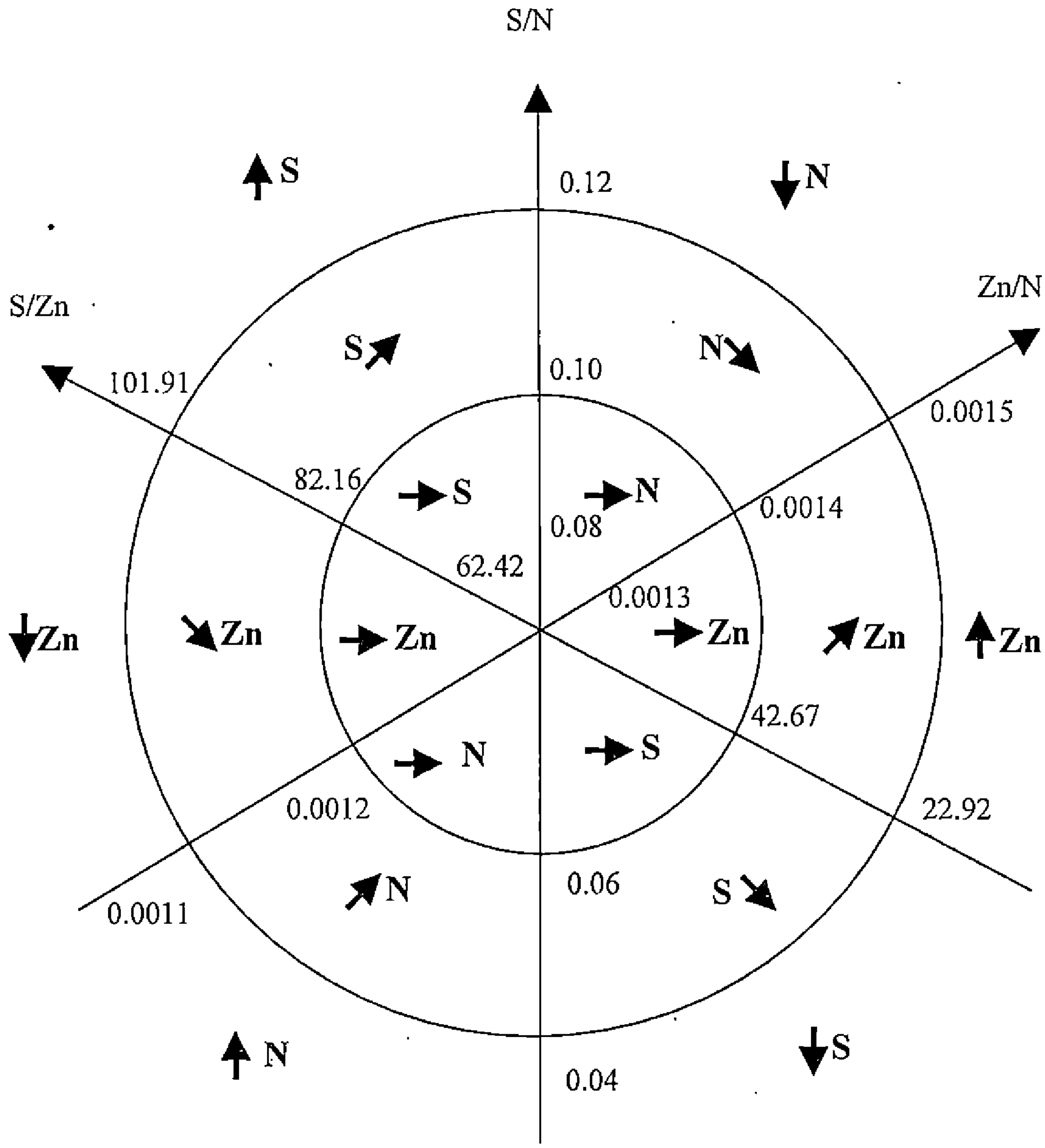

Fig.3 DRIS chart involving N, S and Zn for berry yield in black pepper

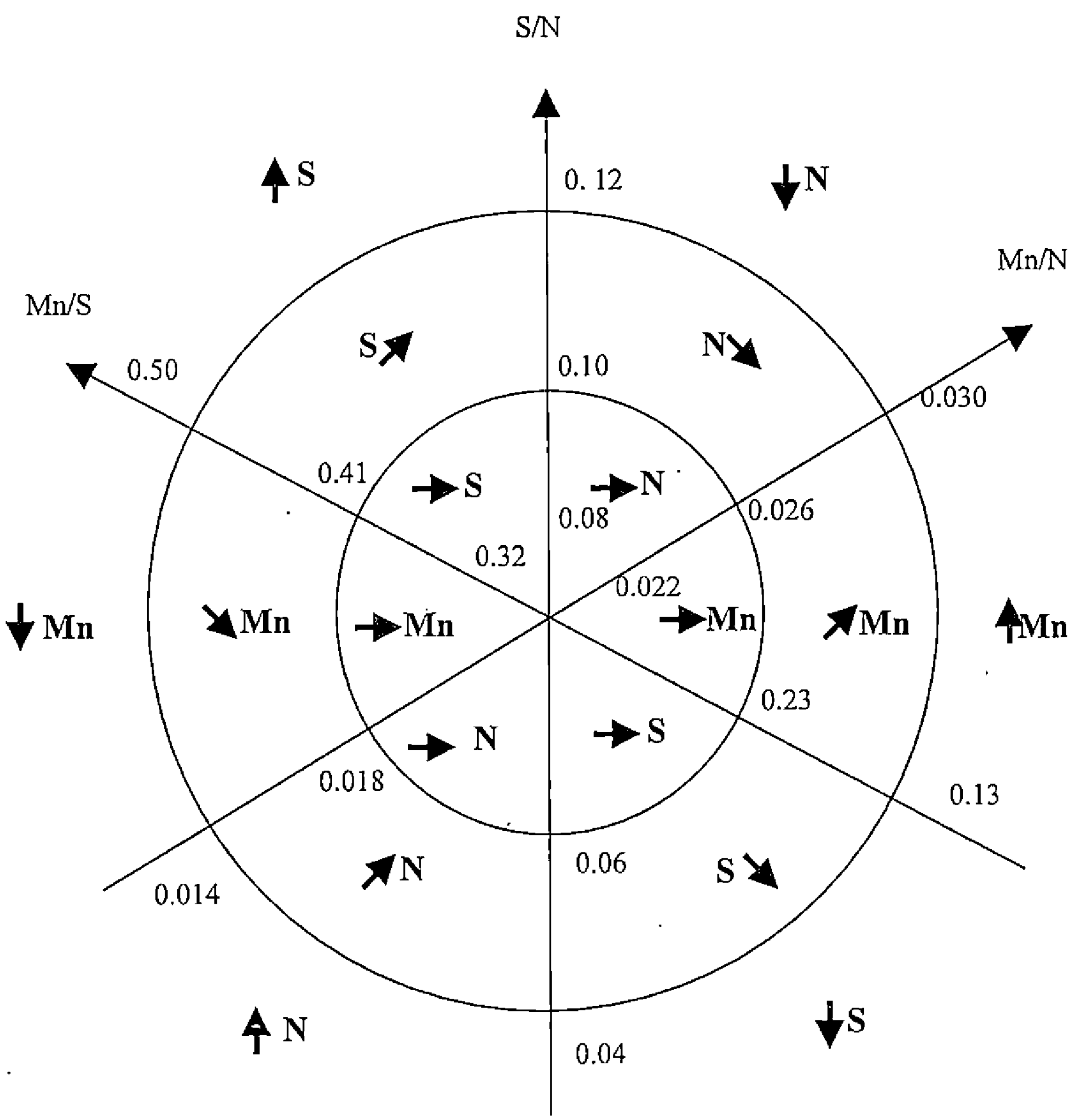

Fig. 4 DRIS chart involving N, S and Mn for berry yield in black pepper

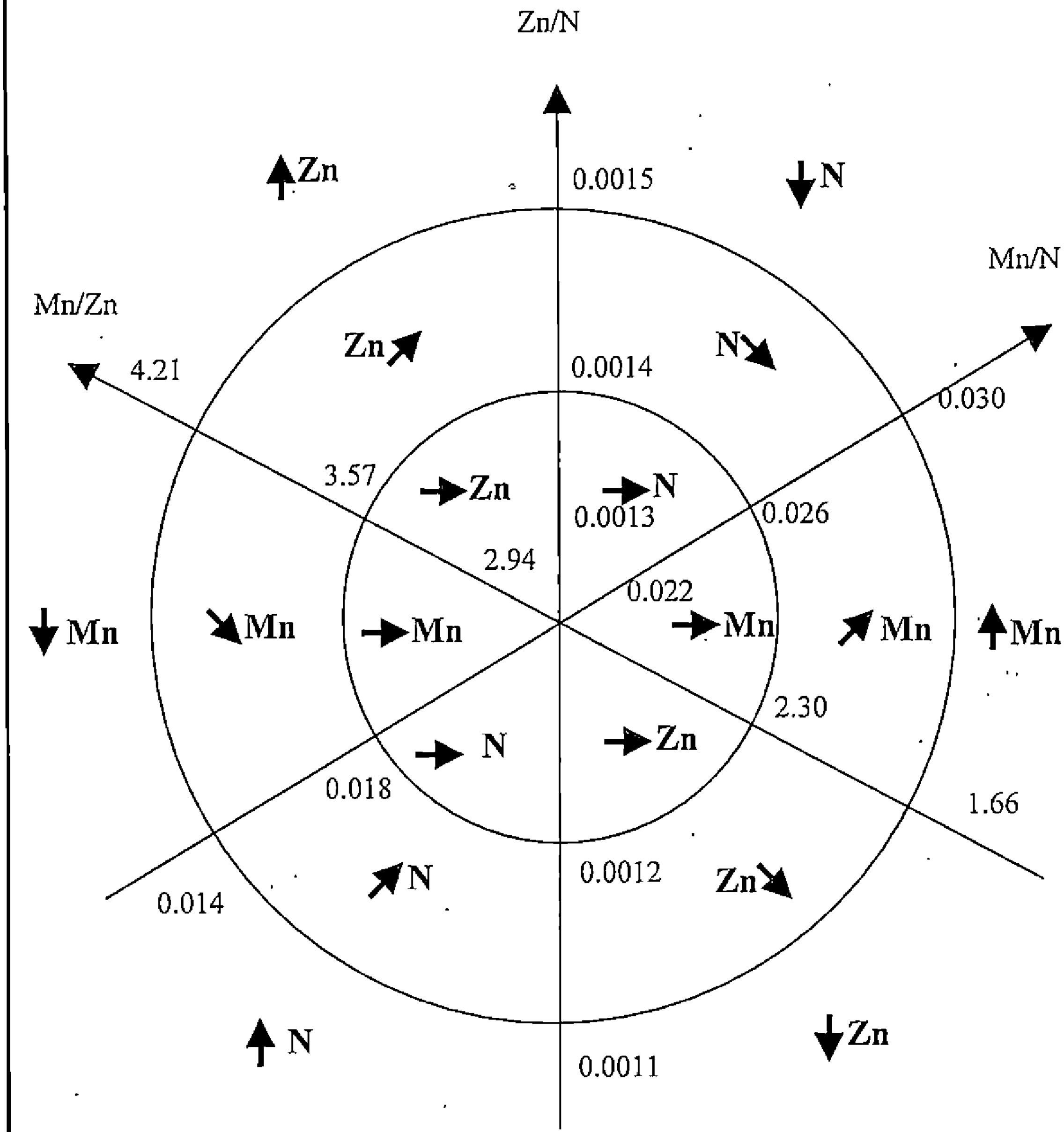

Fig. 5 DRIS chart involving N, Zn and Mn for berry yield in black pepper

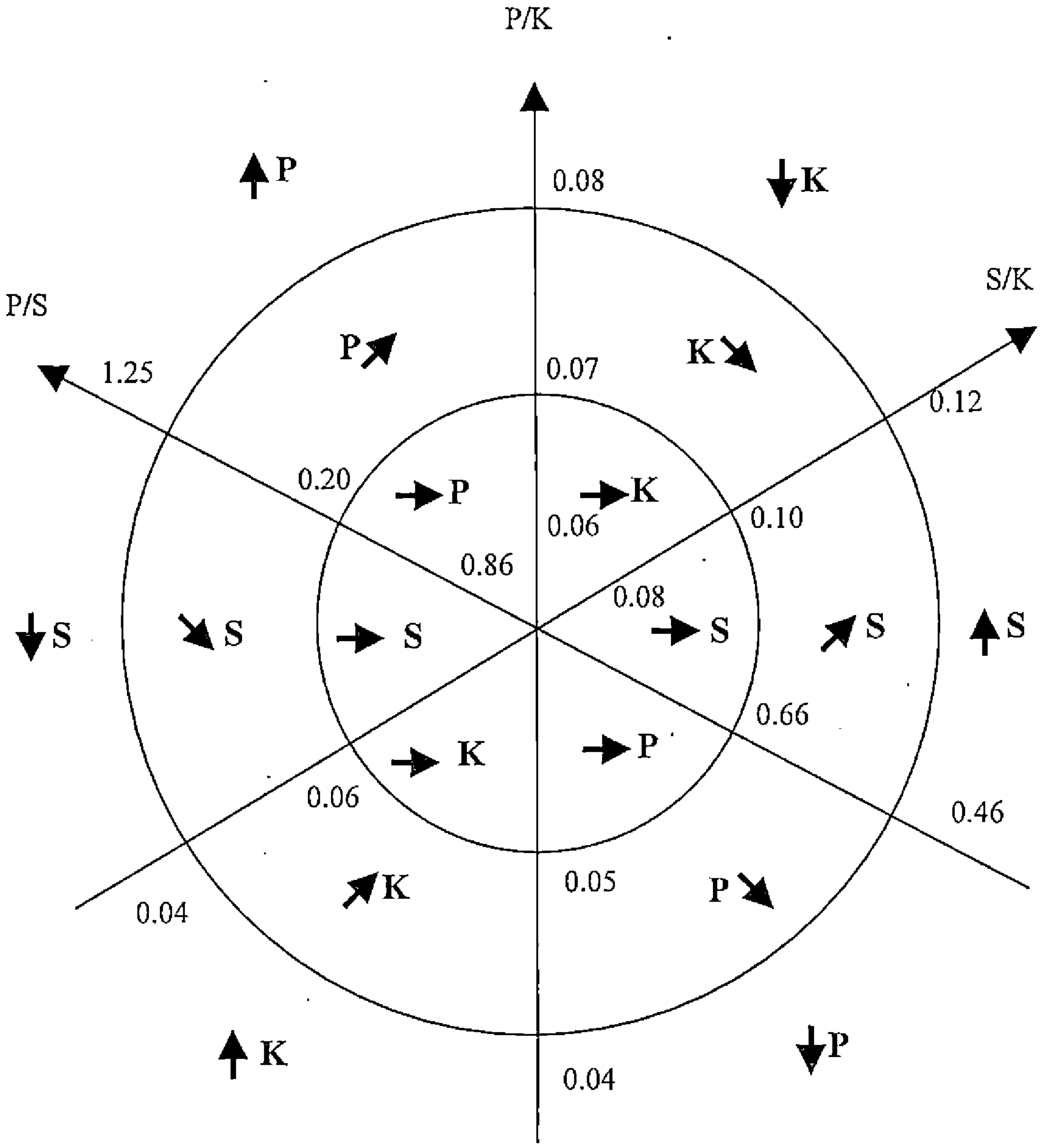

Fig. 6 DRIS chart involving P, K and S for berry yield in black pepper

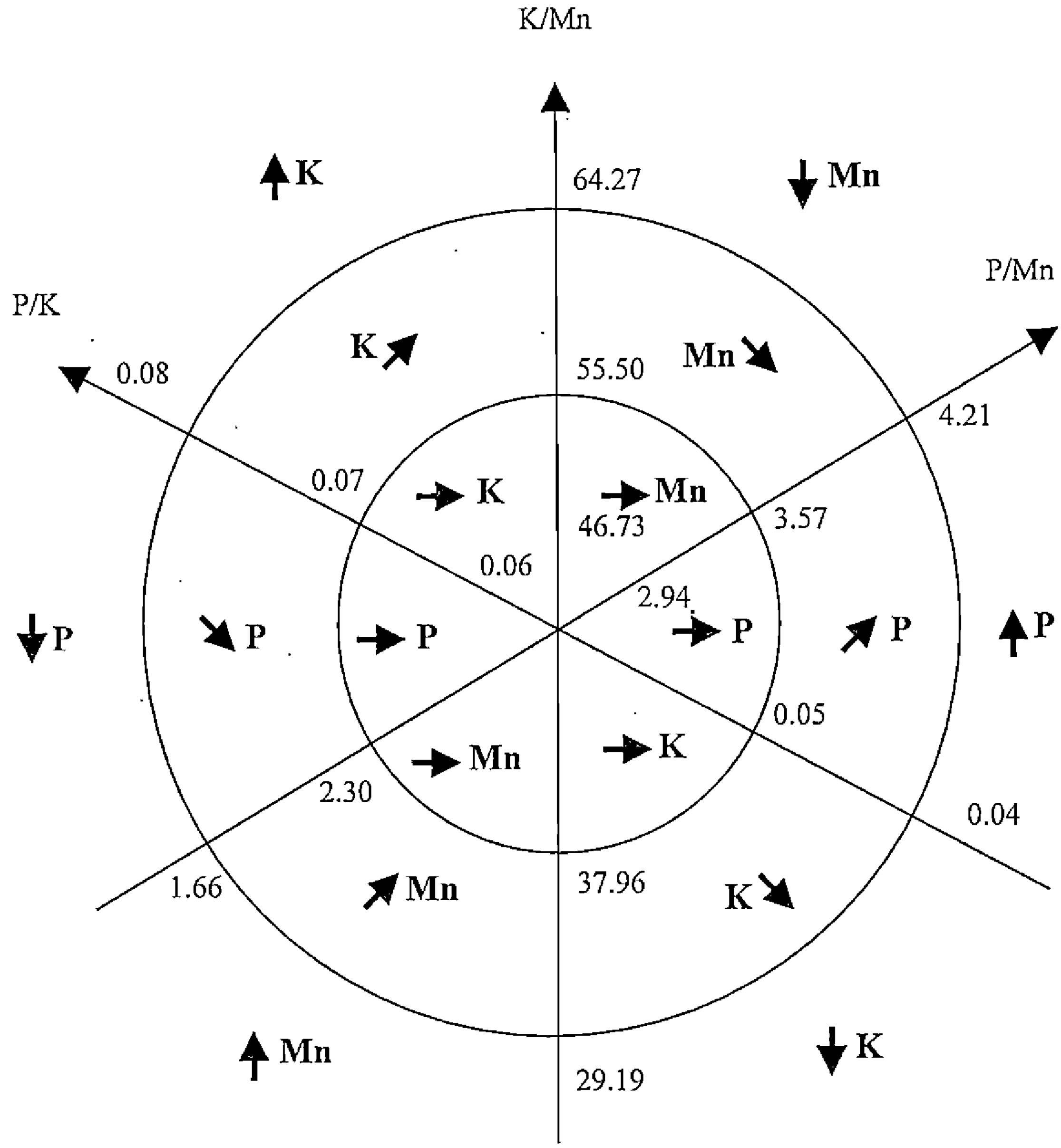

Fig. 7 DRIS chart involving P, K and Mn for berry yield in black pepper

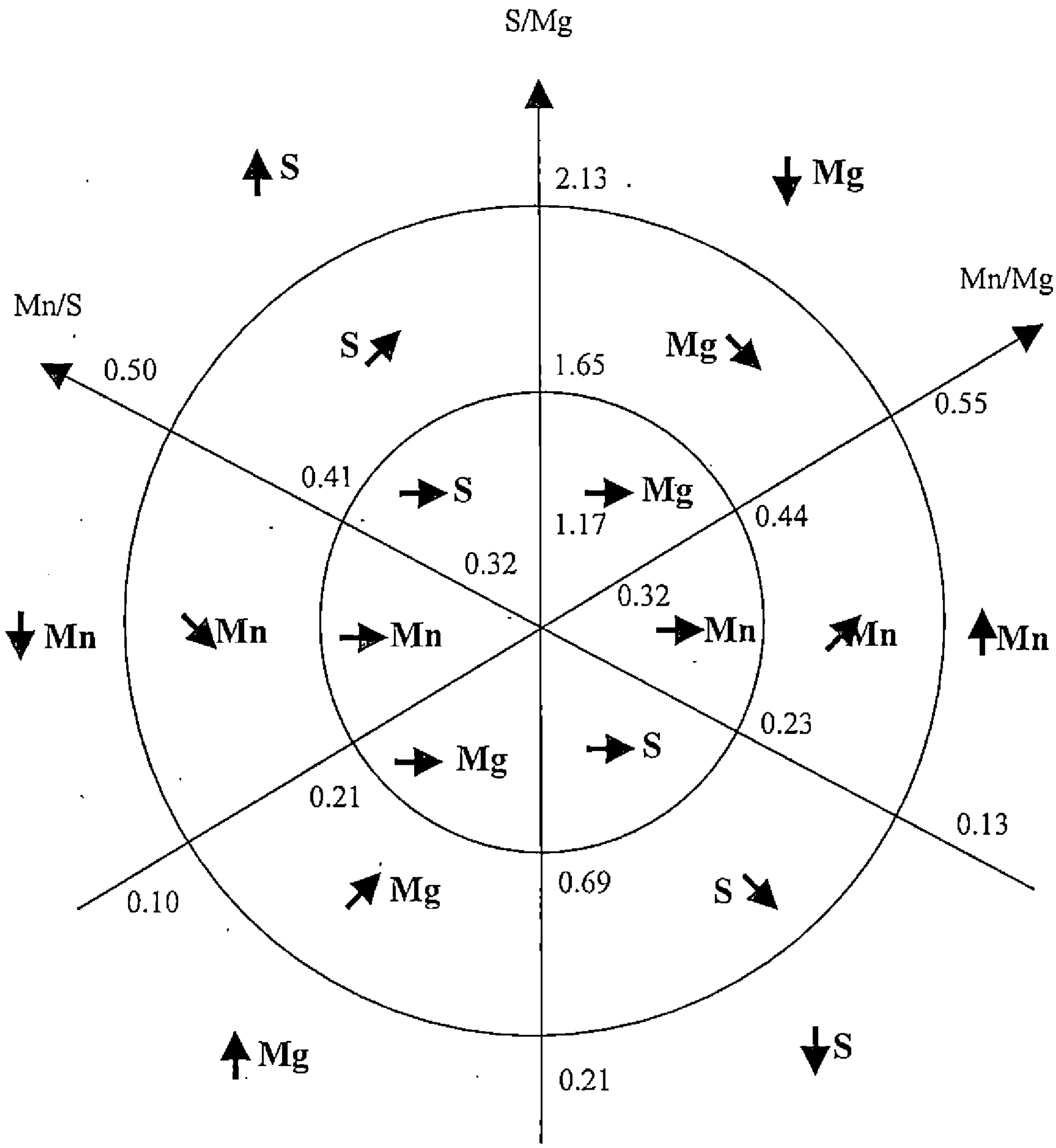

Fig. 8 DRIS chart involving Mg, S and Mn for berry yield in black pepper

DISCUSSION

5. DISCUSSION

The role of foliar elements, viz. N P K Ca Mg S Fe Mn and Zn contents in relation to yield and quality of black pepper was investigated with a view to have a scientifically sound and practically viable management technology for yield improvement. The results of the study are discussed in this chapter.

5.1. Conventional Soil Test

Conventionally the guiding principles in nutritional management of crops are based on soil test data involving major nutrients only, made available through analysing of the composite soil samples. Extreme plant to plant variability in yield expression within the same plantation observed in the present study (Table 6) is the primary evidence to show that such system can not be effective in ensuring at least uniform yield of every plant. Moreover, the soil test data viewed against the soil test classes (0-9 classes) showed that soil is medium high to very high in fertility inspite of very low levels of yield of certain plants.

5.2. Soil analysis of the rhizosphere

In the same way, nutritional management based on analysis of the rhizosphere soil (Table 3) also will appear inadequate to explain the yield variability.

Yield is a function of the metabolic processes of the plant and as such any system capable to express the yield variability should be capable to express foliar variations in the elemental composition. A comparative evaluation of the data in Tables 3 and 4 reveals that magnitude of variation is very small at foliar level as against that of soil. The pattern of variation in soil environment is characteristic to the element concerned, and is no way capable to explain foliar contents even fairly accurately. The variation patterns in the interaction of elements in soil and plant systems (Tables 5, 8a, b and c) as well as their shifting patterns with yield variation is further evidence to show that soil analysis data by itself will be inadequate to explain the variations in yield.

However, the disproportional high variability (Tables 3 and 4) of non-applied elements like secondary and micro nutrients in the rhizosphere and at foliar levels would suggest their positive involvement in the cause of an expressed variability of the order of 86 fold in the same plantation. Prabhakumari (1992) also made such a proposition.

5.3. Inter relations of elements with yield

Nutrients are known as the lubricating agents in the metabolic process of crop production. They are components in a set of chain reaction assigned with varying functions and required in varying quantities to complete the process.

A perusal of the data in Table 7 will show that some elements while showing positive relations, others have shown negative relationships. This would mean that yield is not the direct resultant of any individual element but is the product of negative and positive effects of different elements. In other words, yield is the product of net relationship of positive and negative components. Secondly, the negative relationship of P and K may be due to the continued application of the same level to all plants irrespective of the yield range of 0.16 to 13.80 kg plant^{-1}. In the low yielding ones the P and K may be in excess. Potty and Radhakrishnan (1978) have reported that excess rhizosphere accumulation of P is harmful in coconut. Mathew (1993) was of opinion that nutritional management should be yield based. Another point of interest is the significant influence of native elements on yield. While Zn had a positive effect Mn had a negative effect. These results are indicative of the fact that yield analysis based on major nutrients alone is incomplete.

A further extension to this is revealed from the data in Table 8a, b and c which showed that the phenomenon of interaction of one element is not to another element alone but is spread out to many elements, probably based on ionic nature, bonding strength etc. and that the expressed effect of any element is the net function of the many interactions to which it is subjected at the soil and plant level. These interactions follow different patterns at yield level. Thus nutritional analysis will have to be done at specific yield levels and analysis in such a wide range of yield may prove misleading.

The inevitable ionic level of interactions of elements which depend upon content, valency, bonding strength etc. point out to inactivation among ions will necessarily be limited to essential elements. In such situations sometimes elements treated as non essential and non functional also will have to be considered. The fact that the interactions exist in the plant at a different level and magnitude and the presence of elements other than essential points out to the possibility of involvement of the hither to designated non functional elements also in productivity both at soil and plant level.

5.3. Critical level concept

Critical level of any element is a reference to content of that element in the foliage or plant, and as the yield is a plant function should be expected to show specific relations to productivity. Thus, critical level is defined as the level of an element in the plant beyond which no yield improvement will be obtained.

A perusal of the data in Table 15.a showed that yield levels or increasing pattern of yield is not accompanied by a correspondingly increasing pattern in the foliar level of any element studied in this project. Thus a pattern of the order <1.0, 6.5 and 5.4 kg berries plant^{-1} was obtained at 2.35, 2.33 and 2.52 per cent N respectively, showed that it is not the content of any element *per se* that modulates the yield. Wilcox (1937) reported that ability for yield expression is a plant characteristic, and is linked not to the level of an element but to the capacity of the plant to dilute the content of the element. Content of any element is a function of absorption alone, where as its utilisation will be affected by many other factors. Mathewkutty *et al* (1995) elucidating the causes of negative relationship of nitrogen with yield in coconut had found that the positive effect of nitrogen got masked by a deficiency of sulphur. Similar results had been reported by Musthafa and Potty (1995) in rice where excess content of Fe in plants had masked the response to N. These results suggested that the content *per se* of any element need not necessarily be able to explain the yield variability in crops. This further suggest that any process affected by a number of factors can not be fully explained by any one factor involved. Absorption of an element and yield are basically resultants of two processes affected by different factors also. Hence, theoretically one resultant may not be able to explain another resultant.

Critical level by definition implies the relation ship of an element at very high yield level and has to be based on yield obtained. Variability in yield from place to place will tend to attribute critical level to crop and place. Accordingly, De Waard (1969) fixed critical level of N as 2.7 for Malaysia and Nybe (1986) put it as critical range in the order of 2.1 to 2.4 for Kerala. A location dependant factor may not be able to fully explain a biological process.

The concept of critical level is always linked to time and specific leaf. Data in Table 19 related to the variation of leaf content of N of the order of 2.69

to 3.51 per cent between first and fourth leaf in the same lateral. Similarly, variation in content of N (Table 20) of the same leaf showed variation of the same magnitude over a 9 month sampling period (Sushama, 1982 and Nybe 1986).

Yield in black pepper is a five- step sequential process, viz. flushing, initiation of spike, elongation of spike, berry development and oleoresin development; spread over 6-7 months. It is possible unlikely that levels of a mobile element in any particular leaf at any one time can fully explain the yield process spread over 7 months.

In addition, yield in any crop is not a function of any single leaf. It is an additive contribution of several leaves. Even in small cereals like rice, where productivity phase is only around 50 days, 30 per cent of the yield at least is the contribution of leaves other than boot leaf (Volkmar Stoy, 1969). This erodes further the credibility of total dependence on critical level concept.

A perusal of the nutrient contents and yield variability of the study in the light of the critical levels fixed by Nybe (1986) for black pepper showed that yield variability exists well above the critical range (Table 15.a) which again casts shadows of doubt on total reliance on critical levels.

In black pepper or any perennial crop characterised by 6-7 months productive and 5-6 months vegetative or gestation phase, yield, terminating with flushing, is the sum of the previously accumulated and currently produced carbohydrates. Critical level identified at any one time may not be able to fully explain the yield in such cases.

Yield of black pepper has two components, yield of berries and yield of oleoresin. They are products of different processes and the same level of any element may likely fail to quantify two processes.

These results indicate that the soil test or soil analysis or critical level concept fails to explain the cause of yield fluctuation fully. As such they can not serve as an individually comprehensive base for any specific nutritional management programme.

5.5. DRIS concept

Diagnosis and Recommendation Integrated System known as DRIS was propounded by Beaufils (1973). As the name indicates the system combines two components: Diagnosis of the factors limiting the yield and Recommendation to overcome them. Diagnosis of the yield limiting factors is made by a comparison of the status of high yielding ones and low yielding ones, and the system stipulates inclusion of all identifiable absolute factors that may influence the yield. This comparison between the two realised yield levels ensures reliability and practicability for the system. The system envisages not a mere comparison of the factors at absolute levels but the balance of every factor with all others through these ratios. Thus accounting for all the possible positive and negative interactions that may affect the process, and locating the factors limiting the yield. The system envisages development of DRIS indices from DRIS norms, and NII as the sum of indices. This approach calls for a progressive diagnosis system for step-by-step increase in yield in which NII will decline progressively to zero. This is the maximum yield that can be obtained from the crop.

The DRIS depends on diagnosis, and recommendation based on this diagnosis. It considers factors and their interactions in the progressive yield levels and envisages to reach the maximum attainable, is scientifically sound and theoretically viable. However, the progressive steps and implementation have to be tested and suitably modified in our context.

The DRIS envisages a 5- step process: dividing the study material into discriminating yield groups, working out and comparing the foliar contents for all possible balances and products, DRIS norm development, DRIS indices formulation for ranking of limiting factors, and recommendation.

These steps as applied in this study and aspects of its applicability and modification are discussed hereunder.

5.5.1. Classification of subjective population and application of DRIS norms.

The basic and primary step in DRIS is division of the population into discriminative sub-population of low and high yielding, by adding or subtracting one SD from the mean to develop DRIS norms. This purely mathematical sub division need not hold good as it does not consider the yield level of plants and will assume that in the LYG variation magnitude of the same factor may be limiting the yield in the entire range. This is against the basis of the progressive diagnostic system concept. The data presented in Table 14 on the significant ratios affecting the separate yield classes of LYG, MYG and HYG where 13, 16 and 20 ratios, were found to affect the yield respectively, further point out that the limiting factors shall be different. The variation in NII in the general, and separately to LYG, MYG and HYG in Tables 15.d, e, f and g support this. But the norms developed in the different systems classifying the population did not differ among themselves, which suggested that norms development is independent of the plant factor. Accounting for variability of very high magnitudes is probably at the level of application of DRIS norms. In a perennial crop like black pepper the variability is at plant to plant level and as application of DRIS norms on each plant as in large plantations is cumbersome, micro groupings at progressively increasing yield trends may serve the purpose. A decile system developed for this purpose showed that application of norms at progressive micro levels of yield will help in identifying yield limiting factors at specific yield level. Such a system formed based on yield automatically taken care of the plant factor.

The decile micro yield level classification by sequentialising the DRIS indices serve the purpose of progressive diagnosis without further experimentation but more correctly and scientifically.

Thus the results of the study indicate that in a perennial crop with yield as a produce of differentiation, a micro-classification of the subjective population is necessary unlike in the conventional system to be used in seasonal or annual crops where the low yield population is treated as one group. This is a modification from the normal approach.

5.5.2. Diagnosis

DRIS indices are represented by +ve and -ve signs with +ve signs indicating relatively excess content and -ve sign expressing the relative deficiency (Table 15.b), which serve as the basis of recommendation. The principle employed in effect is application of the specific factor to bridge the deficiency. In effect, the possible negative influence of the elements marked with + factor, if any, is taken into account. This may interfere with the formulation of correct recommendation.

A perusal of the data in Table 15.b showed that it is not real physical deficiency of Zn or N that limited the yield in the decile class 1 or 3 as a lower Zn content in decile class 3 and lower N content in decile class 6 have recorded higher yields. Thus they were relative deficiencies and as such recommendation shall be to overcome the factor inducing relative deficiency. Prabhakumari(1992) reported that excess phosphorus induces metabolic unavailability of Zn. What is required in this case, therefore, will be removal of the influence of excess P. This calls for a proper characterisation of deficiency or excess. The results presented in the Table 15.a showed that the possible range of nutrient content in the plant shall be classified as physically and metabolically deficient, physically sufficient but metabolically deficient, physically and metabolically sufficient, and, physically excess.

In the present study, a combined perusal of Tables 15.a, b and c will show Zn and N in the first decile were physically sufficient but metabolically deficient. Nitrogen in the 6^{th} decile, Ca in 8^{th}, Mg in 9^{th} and P in the 10^{th} decile were physically and metabolically deficient. Phosphorus in the first 4 deciles is in excess.

A closer scrutiny of the DRIS norms in Tables 10, 11, 12 and 13 will help to clarify the classification better. The low content of an element in relation to all other elements is absolutely deficient or physically and metabolically deficient. A high content of an element in relation to all other elements is physically and metabolically in excess. Relative deficiency or excess arises when one element is relatively low compared to some elements and relatively excess when it is in excess compared to some other. Relatively deficient or excess otherwise physically sufficient but metabolically deficient is a situation induced by some other elements, and, the situation can be effectively managed only by inactivating the harmful influence of that causative element. Singh (1970) reported that Fe excess in plant (due to native content) limits the yield in peas and yield increases were proportional to decrease in Fe content. In the present case, application of Zn as per DRIS indices will only be used to neutralise P and will not increase the yield. In other words, Zn application will be to neutralise excess P which shall be neither objective nor fruitful. Only elements that are really deficient need be applied. Similarly, apparent deficiency of Fe observed in 4^{th} and 5^{th} deciles is not a real Fe deficiency but is the influence of K on reducing Fe content. Negative interaction of K and Fe had also been reported by Dev (1993).

Interactions chemically are the result of cationic competitions and their anionic neutralisation the bonding strength varying in the order P and Sulphur (Tisdale *et al.,* 1995). Thus +ve and -ve signs are signs of interactions, and diagnosis to be objective and effective should consider, along with indices, absolute contents and possible ionic interactions.

5.5.3. Recommendations

5.5.3.1. Nutritional intervention

Recommendations are based on the chart of requirement prepared based on the DRIS indices. The erroneous diagnosis given by indices due to negligence of cationic competition and their anionic neutralisation evidently creeps in the chart.

A perusal of the chart in the light of indices and contents will show that phosphorus regularly applied and/or native content has been the limiting factor which has to be overcome, and it is not the least required. It shall be termed an "yield negator".

A perusal of the data in Tables 15.b and c will show that Mn and Fe had been by the above token yield negators allthrough. This called for a differentiation among yield negators by referring to as "applied yield negators" and "unapplied/native negators". Applied negators again will be of two types - elements like P which are invariably applied, and incidentally applied ones like S in Bordeaux mixture spray to black pepper. Thus the "order of requirement" as presented in DRIS (Table 15. c) may better and scientifically be recast as shown in " Diagnosis and Recommendation Tree Diagram "

An observation of the actual content of Zn in Table 15.a will show that Zn content had been the same at 1^{st} and 6^{th} decile with a mean yield of 0.79 and 4.07 kg plant^{-1} respectively, may appear confusing. This would only mean that it

DIAGNOSIS AND RECOMMENDATION TREE DIAGRAM

DIAGNOSIS

YIELD LIMITING INFLUENCES

- YIELD LIMITORS
  - PHYSICALLY & METABOLICALLY DEFICIENT
  - PHYSICALLY SUFFICIENT BUT METABOLICALLY DEFICIENT
- YIELD NEGATORS
  - APPLIED NEGATORS
    - CONVENTIONAL NEGATORS
    - CHANCE NEGATORS.
  - NATIVE NEGATORS.
  - INADEQUATE VEGETATIVE STRUCTURE

EXAMPLES

PHYSICALLY & METABOLICALLY DEFICIENT	PHYSICALLY SUFFICIENT BUT METABOLICALLY DEFICIENT	CONVENTIONAL NEGATORS	CHANCE NEGATORS	NATIVE NEGATORS
P (10^{th} decile)	**Zn** (1^{st} – 6^{th} decile)	**P** (1^{st} – 6^{th} decile)	**S** (9^{th} decile)	**Fe** (All except 4^{th} & 5^{th})
Mg (9^{th} decile)				**Mn** (All except 7^{th} & 9^{th})
Ca (8^{th} decile)				

RECOMMENDATIONS

ADDITIVE	DELETIVE	DELETIVE	CORRECTIVE	AMELIORATIVE	OTHERS
ADDITION OF FACTORS	DELETION OF NEGATORS	DELETION OF NEGATORS	SUBSTITUTION		
EXAMPLES					
APPLY P (10^{th}) Ca + Mg CARBONATE (HIGHER DECILES)	TEMPORARY SKIPPING P	TEMPORARY SKIPPING P	Zn BASED CHEMICALS FOR DISEASE MGMT.	LIME OR DOLOMITE	SKIPPING P GROWTH REGULATORS ADDITION OF N SPIKES REMOVAL

is not an absolute but only a relative metabolic deficiency of Zn which is the result of probably of cationic competition as well as anionic inactivation. This is evident from the comparison for the row 1st and 6th of Table 15:a, which shows that yield has increased up to 4.07 kg from 0.79 kg plant^{-1} with the same level of Zn (29 ppm) but a reduction of P from 0.173 to 0.158 percent and Mn from 636 to 617 ppm. These results would seem to suggest that recommendation can be 'deletive' also and need not be confined to 'additive' process only. Here the recommendation shall be skipping P. DRIS approach also facilitates fixing the type of recommendation which shall be additive, deletive or corrective/ ameliorative. In the ratio level, if an element is deficient in relation to all others it is absolutely deficient and hence additive, if excess - it is deletive. If a non applied element is relatively in excess, recommendation shall be to neutralise this excess with some other element. This can be seen from Table 15.c on ratios where P (applied) and Mn (non-applied) are in excess which require to be deleted and neutralised.

5.5.3.2. Phytopathological interventions

A closer observation of the data in Tables 8.c, 15. c, e and f have shown that in HYG sulphur is excess which would have come only from prophylactic measures of Bordeaux mixture sprays. Recommendation system in DRIS suggests change in the input to some zinc containing fungicides viz. zineb, mancozeb etc. subject to experimentation wherein excess sulphur as copper sulphate present in Bordeaux mixture is prevented.

It appears that this imbalance has come through an inordinate increase in sulphur content in the leaves of high yielding plants, which implies that a reduced sulphur content would have increased the yield further.

The high sulphur content and the resultant imbalances in these plants inspite of common and constant fertilizer use may appear intriguing. Source of excess sulphur appears to be regular prophylactic sprays of sulphur containing Bordeaux mixture. As berries develop on axillary buds high yielding plants have a high vegetative growth limited to 6 m. Each plant in higher yield class gets almost 140g of $CuSO_4$ annually which gets into the soil-plant system of this characteristic organic cycle.

Thus the yield limiting influences of sulphur possibly from prophylactic sprays point out to the necessity of discriminatory selection of inputs in productivity management. Instead of bordeaux mixture, for prophylactic sprays any Zn containing chemicals (zineb, mancozeb etc.) can improve the low yielding plants and high yielding plants. Sulphur inactivation by rootzone placement of Ca may be another alternative or supplementary practice in high yielding plants. However, this will have to be test found by specific experimentation. It has to be added that insights of this sort is an exclusive advantage of the DRIS approach.

5.5.3.3. Morpho-physiological interventions

A basic requirement for yield in any crop irrespective of annuals or perennials is the vegetative structural development of the plant, which develops early and succeeds concurrently in perennials. Very poor yield is a function of poor vegetative development from early phases cumulatively carried forward and supplemented by inevitable partitioning for berry yield, continued over 13 years. This in turn affects nutrient absorption and utilisation. This is the major negation factor affecting nutrient inputs. As in the case of Zn or S, managing the negation factor will improve productivity.

Recommendation for this situation shall be to withhold P, prevent the spike differentiation through the use of growth regulators or the removal of emerging spikes to stimulate more vegetative growth or by addition of N (second in priority list of limiting factors). Data of the Table 15.c indirectly suggest that this shall be practised up to 6^{th} decile. Physical and metabolic sufficiency at 7^{th} decile further points out to the fact that N by itself can not be deficient for low yielders and negative sign is a negator effect - the negator being 'vegetative structure'. Treatment for varying periods for different deciles will facilitate bridging upward the yield in inverse relation with time.

All these technological precision on recommendation depends on the spectrum of coverage of factors. This is evidenced further from the fact that when only NPK are considered, which has been the core in majority of studies, the recommendations are to be confined to them and as evident from the Table 18.a, the recommendation need not hold good. Probably this is the reason of writing 'order of requirement'. Here additive factor will have to be used to neutralise some other deletive factors and need not necessarily link to physiologic efficiency. Walworth and Sumner (1987) have also reported that precision and scientific perfection of the system depends upon the exclusive coverage of factors.

The plant level diagnosis of the limiting influence shall be made up by recommendation to the soil, where again the chemical interactions are inevitable. Thus specificity of recommendation shall be decided by taking into account plant content, DRIS norms and order of limiting influences or factors.

A perusal of the data in Table 15.c will show that in the high yield deciles Ca and Mg are the elements required first in the order of priorities. But data in Table 6 show that increase in Ca or Mg at soil level fail to improve their contents. On the other hand the negative relation of K to yield as well as Ca and Mg content would lead to conclude that the desired objective shall be brought up by withholding K.

Another aspect of recommendation especially in the high yielding situation is to ensure 'stability of performance'. Data on nutrient ratios in Table 14 indicate that more and more of nutrient ratios become significant with progressively high yielding situations, suggesting that high yield situations are hypersensitive even to subtle changes. Mathew (1993) reported that high yielders require larger quantities of all elements as larger quantities are removed and lost.

A confined root system and exclusive feeding zone over the years will lead to exhausting effects on elements leading to excesses of unwanted and deficiencies of the wanted, which may tell upon productivity stability. This will call for more frequent monitoring of deficiency and required recommendation. In other words, this would also imply that rigid and static recommendation for several years, by aggravating both deficiency and excess – will act as a predisposing factor for yield decline and low productivity.

5.6. Quality characteristics

5.6.1. Oleoresin percentage

A plant product is defined by its quality. In the case of black pepper it is the oleoresin content. Data presented in Tables 8.a to 8.c showed that in an ascending yield process, oleoresin yield is a function of the total berry yield, and leans heavily at high yield level to the yield of berries. At low yield levels, the emphasis tends to move to oleoresin percentage, implying that there will be a tendency for reduction in percentage of oleoresin with increase in yield. This would mean that effective oleoresin yield tends to stagnate beyond a level of production in spite of an increase in material yield. This is natural and is to be expected as the oleoresin is a secondary metabolite and as such is the result of other metabolic process. This is substantiated by the data in Table 7 which showed apart from the variation in the relative magnitude of relationship in respect of and Mn negatively. Oleoresin content is affected to any worthwhile extent only by Fe.The constant trend of the differing influence of Ca on yield and quality uniformly and the positive influences of Mg throughout suggest that some balances involving these elements govern the per cent oleoresin content. Data in Table 16 showed that S/Mg and Ca/N ratios directly govern the per cent content of oleoresin. As the yield of black pepper was also affected by increasing S/Mg ratios adversely and Ca/N was of little consequence to yield, the result would mean that nutritional management could be resorted to improve the quality without affecting the yield. In the high yielding plants tilting the S/Mg in favour of Mg and Ca by resorting to plant protection measures with other than bordeaux mixture.

5.6.2. Oleoresin yield

A comparison of the data in Tables 10 and 17 for DRIS norms for berry and oleoresin yield has shown that the factors affecting both of them are the same. This may appear to be confusing as quality and quantity are two different phenomena. The identical result is evidently because of the 86 - fold variation in berry yield and two - fold variation in per cent oleoresin content. Oleoresin yield is the total realised oleoresin yield which with the heavy variation in the yield of berries became pronounced. In other words, it would mean that the ideal programme will be to find out separately the means of yield increase in berries, increase in oleoresin percentage and combining the non - contradictory ones so as to get an increase in berry yield simultaneously with a high percentage of oleoresin in them.

DRIS norms for increase in oleoresin percentage presented in Table 16 indicated that the most significant influence for increasing the oleoresin percentage had been for S/Mg and Ca/N ratios, which suggest that a relative increase in Mg content in relation to sulphur and nitrogen increase in relation Ca shall bring about an increase in oleoresin content without affecting the berry yield.

A comparison with the yield data will reveal that sulphur has been limiting yield in HYG. A reduction in S content itself is sufficient to narrow - down its ratio with all other elements including Mg and paves the way for a higher percentage of oleoresin. An increased availability of Ca may narrow - down the N availability which calls for an increased oleoresin content. Thus an additional dose of N from a non-sulphur containing source along with withholding of S containing prophylactic measures will improve both per cent content of oleoresin and berry yield and thus the total oleoresin yield.

A perusal of the data in Table 15.c will show that in high yield groups Ca and Mg are the elements required from the point of view of yield and their role at least in part is to neutralise the low priority elements like sulphur and Fe since both Ca and Mg can do this simultaneously serving as nutrients. This means that at higher yield levels, application of Ca + Mg and withholding of S will increase quality and quantity. It also appears that the result implies a real inverse relation between yield and quality beyond the level of 11 per cent oleoresin in black pepper.

5.7. Nutrient Imbalance Index (NII)

Nutrient imbalance index (worked out from DRIS norms) is a summed up expression of DRIS indices employed in the study. Data in Table 15.b showed a zig-zag pattern of NII in the present study, though a steadily declining pattern with increasing yield was the expected result. Similar results have been reported by Mathewkutty (1994) also and this has been cast as an instance of unreliability of the concept. Imbalance indices are expression of imbalances among elements, and the magnitude of imbalance depends on ionic nature, valences and quantity of elements.

Secondly, imbalance indices at any yield level is a function of factors considered in the study which is bound to change with variations in the spectrum of coverage of the factors (Table 18 a & b), as in the present study, it would have been as if NPK alone, NPK Ca and Mg, and NPK, Ca, Mg, S, Fe, Mn and Zn were taken. Similarly NII will change based on the yield levels taken for differentiating population in low and high yield groups as is evident from Table 15 .d. In addition, NII is a figure adding up DRIS indices of +ve and -ve signs. As such it is only an indicator and not an absolute index / parameter.

In the same way DRIS indices are also only indicators of the nutrition situation at definite yield levels and are not absolute values. They are indices of guiding principles on what should be the management practice to be adopted for an yield improvement. Thus, a progressive diagnostic process will define the yield process and yield limiting factors progressively. The general pattern of decline in NII with yield improvement points to a stage where NII is zero, which represents the maximum biological yield that can be realised through management efforts. In the present study the maximum yield attainable through objective management appears to be well above 13 kg plant^{-1} with quality above 11.0 per cent oleoresin content.

5.8. DRIS chart

DRIS chart is the graphic representation of the real position in relation to balances and imbalance of any one element with the other two elements. This calls for the preparation of several charts to depict the situation depending on the factors studied.

A perusal of the data on Table 21 will show that dependence on statistically significant ratios alone as Mathewkutty (1994) had pointed out, will not aid depicting all the balances in the DRIS charts which in turn run contrary to the concept of DRIS. This would suggest that all the ratios with maximum variance ratio should be selected. Preparations of all the possible charts as in the case of this study showed that an element in balance with another shall be in imbalance with another. DRIS charts will help us know what should be the pattern of requirement. Physiological environment shall be ensured by the addition, deletion, ameliorative/corrective measures individually. In the present study withholding of P up to an yield level of 5 kg plant^{-1}, amelioration of Mn by liming and application of nitrogen together becomes the recommendation for the low yielders.

5.9. Influence of nutritional factors on imbalance indices

Data on DRIS indices prepared with three elements alone, five elements alone and nine elements presented in Tables 15.b and 18 .a & b showed that the indices will be different at different levels of factor involvement. This is evidently because of the fact of leaving out many factors and their interactions, and suggest that the reliability of DRIS approach depends on the consideration of as many factors as possible. The negative interactions of Mn and positive interactions of Zn and their involvement in deciding the yield as well as the negative interactions of P and K can only be found in such an analysis where contents and balances are analysed. This unique advantage of DRIS makes it a better system compared to critical level and other concepts.

5.10. GENERAL DISCUSSION

An overall scrutiny of the data will reveal some unique aspects of the concept of DRIS, its superiority over conventional methods, and its sole dependence especially in higher fertility environments. The study also has pointed out to certain limitations as it is currently employed, and possible modifications by which it shall still be perfected more.

Conceptually and in practice DRIS envisages characterisation of the validity of yield factors of low and high yielding plant groups and tries to simulate the situation of high - yielding ones in the low - yielding group. The very concept ensures adaptability, possibility of achievement and success of the effort. Hence it can be termed as an objective approach and success - ensured - system. Since recommendation is based on indices from high -yielding ones it is auto -validatory.

DRIS, as it is a totally plant - based system. The entire five - step process involved in diagnosis-discriminative division into low - and high-yield subgroups, analysis of contents of both, working out DRIS norms based on variation in ratios, development of DRIS indices, and preparation of the order of requirement and the recommendation made is confined to the plant. As the requirements and balances are linked to the process of yield formation, which is a plant function, it is a physiological system transformed into the practical plane, and assurance of results has its base on this aspect.

It is probably because of this base in the metabolic relations, this system is able to explain yield - limiting factors when available elements are moderately high to very high in soils (Table 3) and plant contents (Table 4) of nutrients exceed critical levels.

The DRIS also encompasses the agrobiological principles (Wilcox, 1937) that yield is related to dilution of nutrients and the yield nutritional range characteristics (Massey, 1936).

The decreasing trend in the NII and DRIS indices with progressive build up of limiting factors will enable one to identify the maximum realisable yield by bringing up all the limiting factors to zero (Table 15.a). No other system offers this possibility and in this context it is supplementary to the concept of "Liebigs law of minimum", which speaks only of the progressive increasing trend with increase in respective growth factors.

Adoption of DRIS concept accounts for natural and native factors like Fe, Mn content of soil etc. in addition to applied factors. Conventional system of soil test or critical level concepts do not do this and hence can be designated as only "partial systems". The conventional systems do not consider the inter relations between quality and quantity. But DRIS can frame a technology specifically for yield and quality separately and in integration. Its uniqueness shall all be summed up that it is a "cause and effect relationship".

The concept of one DRIS norm will suffice in a seasonal or annual crop. But in perennial crops with gestating structural development phase and early yield development phase more than one norm will be required. In such situations development of DRIS norms will be required as the requirements are different in different "growth milestones". Black pepper being a creeper with its characteristic column canopy formation, its management based on growth milestone in optimum vegetative structure development assumes prime importance. It appears that the wide variability in yield in black pepper observed in the study (Table 6) may be the result of lack of differential manuring in phases in inadequate morphological developments.

In a diagnosis and recommendation integrated system, diagnosis is at the plant level and recommendation at the soil level. The recommendation part is apparently very little developed unlike the fool-proof diagnostic part. The interactions among elements at the soil and plant level observed in the present study (Table 5 and 7) will suggest that a judicious objective oriented recommendation system shall be developed. The variability in the interaction of elements at soil, soil to plant and at plant level suggests characterisation and quantification of these relations.

Characterisation of the pattern of interaction among elements at soil, soil to plant and at plant level considering the ionic characters of the elements is a pre-requisite for this. Based on them targeted production plans and graded productivity improvement programmes for different productivity levels shall be framed and success achieved with a fair degree of accuracy.

Production plan for targeted yield in black pepper

Targeted yield	Management Practices
Upto 3.5 kg $plant^{-1}$	• Temporary skipping of P • Promoting vegetative growth (Growth regulators / spike removal) • Addition of Zn and N
3.5 to 5.0 kg $plant^{-1}$.	• Neutralisation of Fe and Mn • Application of N, K in the order
Above 5.0 kg $plant^{-1}$.	• Neutralisation of Fe and Mn. • Application of Ca + Mg carbonates. • Substitution with Zn based fungicides. • Application of K, N , P in the order.

In the light of the present study, a plan for 3.7 kg berry yield $plant^{-1}$ shall be achieved by temporary withholding of P as well as neutralising excess Fe and Mn. Application of N, Zn and K will be required to increase the yield up to

5 kg plant^{-1}. At higher yield levels neutralisation of excess Fe, making up deficiency of Ca and Mg and substitution of bordeaux mixture prophylactic sprays with non- sulphur containing compounds shall be expected to improve the yield.

The results taken together enable to quantify in a graded way the progressive yield process of the plant.

SUMMARY

6. SUMMARY

The main results of the study entitled " Development of Diagnosis and Recommendation Integrated System (DRIS) in black pepper (*Piper nigrum* L.) in relation to yield and quality characteristics " conducted during 1993-96 to evolve a viable diagnosis and recommendation system for productivity improvement of black pepper are presented below.

1. The study showed that the non-genic variability in yield and quality in black pepper is very high. Yield of berry varied from 0.16 to 13.8 kg plant^{-1} and oleoresin content from 7.0 to 15.5 percent though the crop was under the same management and macro-climatic conditions. The distribution pattern of yield and quality of the plant conformed strictly to the normal distribution.

2. As per soil analysis, the soil of the experimental site came in the medium high to very high group in respect of organic carbon, available P and exchangeable K.

   Detailed analysis for pH, organic carbon, available P, K, Ca, Mg, S, Fe, Mn and Zn in a representative micro population showed very wide variation among all the elements. The soil pH ranged from 4.3 to 6.8, organic carbon from 1.03 to 2.16 per cent, available P from 3.87 to 26.54 ppm, exchangeable K from 128 to 560, Ca from 144 to 1324, Mg from 26 to 156, available S from 11.7 to 131.9, Fe from 19.9 to 55.9, Mn from 37 to 98 and Zn from 0.9 to 4.5 ppm. Calcium showed the highest and Zn minimum variability. These variations suggested possible specific plant effects on soil in turn indicating that each is a soil-plant interaction system in itself.

3. Foliar status of elements showed that N ranged from 1.61 to 2.94 per cent, P from 0.102 to 0.251, K from 1.60 to 3.40, Ca from 1.00 to 2.82, Mg from 0.101 to 0.562, S from 0.103 to 0.488 per cent, Fe from 114 to 808 ppm, Mn from 200 to 990, and Zn from 18 to 43 ppm.

Except N, all the elements were above the critical level as per those fixed by De Waard(1969). The tentative critical level proposed by Nybe(1986) was also below what was observed in the present study in respect of N, Mn, Fe and S.

Direct correlation studies conducted showed positive relationship of yield with N, Mg and Zn, and negative relationship of P,K, S and Mn. Positive correlation of some and negative correlation of some other elements to yield showed that no single element in itself can explain the productivity relations of nutritional influences.

4. Inter - correlations worked out between yield and nutrient contents at different yield group levels differed among themselves. Zn was related to yield positively and Mn negatively in medium yield group. In the high yield group P and S were negatively related. These results showed that the relationship of elements was different to productivity at different levels and the possible limiting influence of elements varied at different yield levels. These results suggested that any objective analysis of nutrient-yield relations should also take into account the levels of yield of the crop, especially in perennial crops.

5. The inter relations of nutrient ratios to productivity revealed that more ratios get involved with progressive increase in yield. At low levels of yield (<2.5 kg plant^{-1}) 13 ratios were found significantly related as against 16 in medium yield group (2.5 to 5.0 kg plant^{-1}) and 20 in high yield group (>5.0 kg plant^{-1}). The results also indicated that at low levels of yield excess of native elements limited the yield and at higher levels accidentally high sulphur received probably by way of prophylactic spray of bordeaux mixture against fungal disease, limited the yield.

6. Nutrient ratios were found to be better indicators of black pepper productivity as they accounted for interactions among them as well. Reliability of the information was found to increase with increase in the number of elements and the interactions among them studied.

7. The population of 1100 plants was divided into low and high yield sub-populations and the nutrient ratios of the high yield sub-population constituted the general diagnostic norms. The efficiency of this general DRIS norm was further tested by evolving three sets of DRIS norms specifically for LYG, MYG and HYG. The results showed that they did not differ in efficacy and that the general norms shall be applied at population classified in progressive yield levels.

8. Application of DRIS norm at specific yield level showed that the system helped to identify the yield limiting factors linked with current yield. A classification of the population into deciles (10 yield classes) and application of DRIS norms gave the specific limiting factors at the 10 yield levels. Results showed that upto an yield level of 3.77 kg plant^{-1} the limiting factor was Zn, upto 5.0 kg plant-1 limiting factors were Zn, N and K. In the later deciles they were Ca and Mg, and beyond 7.0 kg plant $^{-1}$ it was P and Ca.

9. An examination of the DRIS indices in the light of contents and variation pattern of elements with yield revealed that limiting influence of any factor can be under two situations in black pepper:

   i) a physical and metabolic deficiency.

   ii) a physical sufficiency but a metabolic deficiency.

   The second situation shall be due to the interaction by some other element ranked towards the final positions. In the present study the deficiency of Zn in the low yield class or lower deciles had been due to a metabolic deficiency in spite of physical sufficiency of Zn. Metabolic deficiency of Zn appeared to be due to an excess P content.

   Similarly in the higher yield class or higher deciles, Mg and Ca identified as limiting, limited the yield though a physical and metabolic deficiency of the element as well as due to a physical excess of Fe, S and Mn.

10. DRIS indices are bound to vary based on contents and magnitude of interactions of nutritional factors involved and as such are qualitative expressions. Results showed that they need not necessarily decrease with progressive increase in yield.

11. Comparison of the number of factors studied in relation to nutritional influences on productivity showed that diagnostic results will vary depending upon the number of factors. When the number of factors is smaller the reliability will be less and even misleading.

12. Results showed that recommendation part has three dimensions; it shall be additive, deletive and ameliorative or corrective or their combinations and need not be additive all the time. Situations of only physical sufficiency

but a metabolic deficiency as in the present case of low yield group, of Zn, can be corrected by withholding P. Physical and metabolic deficiency of N, Zn and K can be corrected by the application of N and Zn while withholding P in the medium yield group. In the high yield group, prophylactic spray of bordeaux mixture should be substituted with zineb or any other zinc - based chemical or Mg has to be supplied as it is physically and metabolically deficient, and Ca may be given to ameliorate harmful effects of S, Fe, and Mn. In the case of plants yielding beyond 7 kg P, Ca and K have to be applied.

13. Oleoresin yield followed the pattern of berry yield in all respects. High oleoresin yield of 1.69 kg was realised when the berry yield was 13.8 kg plant $^{-1}$.

14. Oleoresin per cent of black berries ranged between 7.0 and 15.5. It was largely independent of yield of berries and was found to be affected by Ca/N and S/Mg ratios. The possibility of increase in oleoresin per cent without affecting yield is indicated.

15. Nutrient Imbalance Index (NII) analysis showed that progressive diagnosis and recommendation can still increase the yield of black pepper even in the highest yield class. The results suggested possibilities for improving both the qualitative and quantitative productivity through an independent but specific, management system.

16. DRIS charts which show graphical representation of deficiency - excess relationship is limited only for instance of a three factor analysis whereas interaction of any two elements is not confined to any two elements.

17. The near constancy of foliar nutrient ratios against changing levels of contents over age and sampling time demonstrated the reliability of nutrient ratios in explaining the limiting influences on productivity better than contents.

18. A comparative perusal of the different methods for characterising nutritional productivity relationships showed that DRIS based approach is the most comprehensive and scientific. It encompasses all the nutritional laws on productivity as it takes into account, content, positive and negative interactions and as many factors as possible and is based on yield process and metabolic utilisation. It is more reliable and predictable as it aims at simulating the situation of high yield plants.

19. It has also the twin unique advantages that it offers a system of progressive diagnosis and progressive management to get maximum biological yield obtainable through nutritional manipulation.

    This is the only system which can be depended upon in situations of high soil fertility.

20 The pre-requisite necessity of each morphological development to attain the potential for productivity and its longer temporal requirement necessitate a specific DRIS development to be preceded by DRIS for productivity.

21 Critical analysis of the factors involved , their interactions and reflections through indices aid in step-down analysis of observations and identifying progressive management. The results have pointed out morpho-physiologic development of the plant as a pre-requisite to bridge the gap in productivity by improving very poor yielders by inhibiting differentiation and stimulating vegetative development through the addition of N and use of growth regulators for varying periods.

22 The complete and comprehensiveness of the plant - based diagnostic part requires to be followed up in recommendation part as it is in the soil where variability in the content and interaction among elements at soil and soil-plant levels have to be viewed at reactivity level, possibility for this is established in this study.

23 The study has aided in constructing a tower of yield process in relation to management representing the conceptual step-wise management required to substitute the present system.

24 A targeted production plan developed based on the data revealed that temporary withholding of P, and application of N and K, substituting bordeaux mixture spray, soil amelioration with Ca + Mg carbonate shall be the principal management steps to raise the yield to 7 kg $plant^{-1}$.

FUTURE LINE OF WORK

- Productivity is the result of proper progressive development. Stable high yield results several years after planting, comprising early vegetative phase and progressive improvement in yields reaching to stable yield levels. These distinct phases shall be designated as growth milestones. Requirements for these specific milestones will have to be worked out.

- As the interactions among nutrients influence the recommendation to be made, the phenomenon of interactions at soil and at plant level needs to be characterised in relation to quantity, intensity and release characteristics in the soil and quantitative relationships in the plant.

- Alternate bearing habit in relation to nutrition also will have to be investigated.

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* Originals not seen

APPENDICES

Appendix 1 Meteorological parameters of R.A.R.S, Ambalavayal from 1992 to 1997

Month	1992					1993					1994				
	Temp. (^{0}C)		Rel. Hum.(%)		Rain	Temp. (^{0}C)		Rel. Hum.(%)		Rain	Temp. (^{0}C)		Rel. Hum.(%)		Rain
	Max.	Min.	FN	AN	(mm)	Max.	Min.	FN	AN	(mm)	Max.	Min.	FN	AN	(mm)
Jan	27.7	14.1	75.8	29.4	Nil	27.8	14.0	81.9	30.3	Nil	27.5	15.5	88.7	47.5	74.6
Feb	29.1	16.8	92.6	46.8	0.6	29.3	16.8	79.4	38.7	11.6	28.7	17.4	90.5	47.2	0.6
Mar	32.5	17.6	83.9	34.5	Nil	29.7	17.6	87.0	51.3	69.8	31.3	18.5	86.3	40.0	15.8
Apr	31.6	19.3	89.2	49.4	44.4	30.2	19.0	91.0	60.0	197.8	29.2	19.1	89.6	64.2	202.6
May	29.3	19.5	91.3	66.8	234.0	29.6	19.6	87.9	62.6	220.6	26.9	19.0	90.6	64.2	198.0
June	24.9	19.0	93.6	82.6	587.0	25.9	19.1	92.8	76.7	377.6	24.3	18.2	92.1	83.4	541.6
July	23.9	18.1	92.8	81.7	535.2	23.8	18.4	93.4	83.5	483.6	23.6	17.7	91.2	82.0	885.6
Aug	23.9	18.4	93.0	82.1	315.2	24.4	18.5	93.2	78.3	271.6	24.6	17.5	90.8	82.1	238.0
Sept	25.9	18.2	93.0	75.8	196.0	26.2	18.4	88.5	70.7	66.4	26.4	16.8	88.2	72.2	173.2
Oct	25.9	18.4	91.8	72.7	181.6	25.4	19.3	90.7	75.1	335.0	26.6	16.8	91.5	77.3	231.0
Nov	25.5	18.0	91.3	67.2	224.8	26.2	17.8	87.8	62.8	46.4	26.1	15.2	88.8	64.1	131.2
Dec	26.0	14.5	87.1	48.0	Nil	25.8	16.0	87.9	57.6	47.6	27.3	12.9	86.2	45.5	Nil

Contd ii

Month	1995					1996					1997				
	Temp. (^{0}C)		Rel. Hum.(%)		Rain	Temp. (^{0}C)		Rel. Hum.(%)		Rain	Temp. (^{0}C)		Rel. Hum.(%)		Rain
	Max.	Min.	FN	AN	(mm)	Max.	Min.	FN	AN	(mm)	Max.	Min.	FN	AN	(mm)
Jan	27.7	13.5	85.6	44.9	2.6	28.2	12.1	80.4	40.6	19.2	26.4	15.9	90.0	53.0	21.0
Feb	29.9	15.6	88.0	43.3	88.0	29.5	14.8	82.9	37.0	Nil	28.5	16.6	89.0	43.0	21.8
Mar	31.5	16.7	94.6	38.1	2.6	32.3	17.8	88.1	34.6	Nil	30.1	17.9	92.0	46.0	53.8
Apr	30.4	17.4	88.1	55.2	261.2	30.6	19.5	90.5	56.6	131.6	29.5	19.0	89.0	51.0	138.6
May	28.3	17.4	89.3	66.3	253.4	29.5	20.0	88.5	61.4	121.8	29.6	20.2	91.0	60.0	101.8
June	26.3	16.9	91.1	77.8	253.6	26.6	19.0	90.1	72.5	446.4	26.9	19.9	91.0	74.0	305.0
July	24.3	16.5	92.5	81.3	513.6	24.4	18.6	90.6	79.5	408.8	24.7	19.3	94.0	84.0	527.4
Aug	25.4	16.6	92.6	80.2	442.0	25.1	18.6	91.5	77.6	251.4	24.7	18.8	91.0	79.0	379.8
Sept	26.3	15.6	90.6	70.5	199.8	26.0	18.7	91.2	78.8	252.8	26.3	18.9	91.0	78.0	164.0
Oct	27.1	15.8	91.5	69.3	222.6	26.3	17.7	91.0	73.8	368.4	27.2	18.7	92.0	73.0	237.0
Nov	26.5	14.8	90.0	65.8	116.0	26.3	17.7	89.1	63.3	49.8	26.6	19.0	93.0	77.0	160.6
Dec	27.2	11.0	78.2	35.4	Nil	25.1	15.7	88.8	57.9	130.6	26.8	18.2	94.0	68.0	40.0

Appendix II Relevant data for DRIS norms for yield of berries in black pepper
(n = 1100, Berry.yld. Mean = 3.969983, SD =2.282686)

Ratio	Low yield group (A), n = 201			High yield group (B), n = 185			Var.ratio (SA/SB)
	Mean	Var.(SA)	CV %	Mean	Var.(SB)	CV %	
N	2.322	0.081	12.26	2.396	0.053	9.64	1.52^
P	0.169	0.001	22.38	0.145	9.670*	21.41	1.47^
K	2.450	0.109	13.48	2.315	0.112	14.44	0.97
Ca	1.728	0.109	19.09	1.744	0.118	19.72	0.92
Mg	0.189	0.012	59.07	0.212	0.016	59.50	0.78
S	0.204	0.007	42.29	0.188	0.005	38.20	1.44^
Fe	0.023	0.910*	42.43	0.022	1.460*	54.78	0.62
Zn	0.003	0.000*	18.78	0.003	0.000*	17.33	1.07
Mn	0.060	2.780*	27.58	0.053	1.970*	26.58	1.41^
N/P	14.470	13.970	25.83	17.171	12.984	20.98	1.08
N/K	0.966	0.033	18.78	1.058	0.036	18.03	0.90
N/Ca	1.391	0.096	22.33	1.430	0.103	22.49	0.93
N/Mg	15.705	45.602	43.00	14.967	49.479	47.00	0.92
N/S	13.239	25.470	38.12	14.453	25.842	35.17	0.99
N/Fe	117.233	1565.074	33.75	126.590	1588.936	31.49	0.98
N/Zn	796.995	27840.641	20.94	782.029	20419.311	18.27	1.36^
N/Mn	41.789	201.650	33.98	48.932	225.679	30.70	0.89
P/N	0.074	3.480*	25.33	0.061	1.900*	22.57	1.84^
P/K	0.070	2.530*	22.84	0.063	1.640*	20.25	1.54^
P/Ca	0.101	9.560*	30.53	0.086	5.850*	28.01	1.63^
P/Mg	1.133	0.280	46.71	0.913	0.227	52.17	1.24
P/S	0.943	0.135	38.94	0.855	0.090	35.02	1.50^
P/Fe	8.458	9.580	36.60	7.638	7.734	36.41	1.24
P/Zn	58.339	304.118	29.89	48.042	243.142	32.46	1.25
P/Mn	3.033	1.342	38.19	2.935	0.913	32.56	1.47^
K/N	1.071	0.039	18.50	0.976	0.033	18.49	1.20
K/P	15.166	13.067	23.84	16.455	11.503	20.61	1.14
K/Ca	1.467	0.108	22.41	1.375	0.096	22.55	1.12
K/Mg	16.604	53.097	43.88	14.585	53.371	50.09	0.99
K/S	13.971	30.013	39.21	13.910	25.230	36.11	1.19
K/Fe	123.514	1744.778	33.82	123.201	1831.059	34.73	0.95
K/Zn	845.597	39944.078	23.64	765.112	40333.570	26.25	0.99
K/Mn	44.131	246.826	35.60	46.728	173.029	28.15	1.43^
Ca/N	0.753	0.025	21.09	0.735	0.027	22.33	0.94
Ca/P	10.759	9.662	28.89	12.503	12.376	28.14	0.78
Ca/K	0.717	0.026	22.58	0.767	0.033	23.75	0.79
Ca/Mg	11.707	30.275	47.00	10.738	26.622	48.05	1.14
Ca/S	9.829	15.960	40.65	10.550	18.265	40.51	0.87
Ca/Fe	88.107	1192.974	39.20	92.871	1237.216	37.87	0.96
Ca/Zn	593.102	23283.561	25.73	576.977	31801.039	30.91	0.73
Ca/Mn	30.607	97.793	32.31	34.859	95.882	28.09	1.02
Mg/N	0.083	0.003	61.05	0.089	0.003	60.77	0.87
Mg/P	1.164	0.489	60.04	1.533	0.977	64.48	0.50
Mg/K	0.079	0.002	61.98	0.094	0.003	62.10	0.70

Contd iv

Mg/Ca	0.113	0.005	61.66	0.125	0.006	62.04	0.82
Mg/S	1.077	0.627	73.49	1.289	0.925	74.59	0.68
Mg/Fe	9.425	40.903	67.86	11.003	52.693	65.97	0.78
Mg/Zn	64.707	1565.915	61.16	70.075	2116.258	65.65	0.74
Mg/Mn	3.383	5.345	68.35	4.208	6.519	60.68	0.82
S/N	0.089	0.001	43.10	0.079	9.220*	38.42	1.59^
S/P	1.238	0.274	42.25	1.311	0.197	33.85	1.39^
S/K	0.084	0.001	43.35	0.082	9.950*	38.31	1.34^
S/Ca	0.122	0.003	44.91	0.112	0.002	42.17	1.34^
S/Mg	1.371	0.694	60.77	1.173	0.519	61.40	1.34^
S/Fe	10.166	25.922	50.08	9.798	21.317	47.12	1.22
S/Zn	70.913	1285.196	50.55	62.417	877.384	47.46	1.46^
S/Mn	3.641	3.334	50.15	3.769	2.434	41.40	1.37^
Fe/N	0.010	0.190*	44.91	0.009	0.230*	52.13	0.85
Fe/P	0.140	0.005	48.87	0.156	0.007	54.69	0.64
Fe/K	0.009	0.180*	45.00	0.010	0.350*	60.05	0.51
Fe/Ca	0.014	0.440*	48.55	0.013	0.630*	60.06	0.70
Fe/Mg	0.148	0.007	54.47	0.134	0.009	69.76	0.75
Fe/S	0.127	0.005	56.99	0.130	0.007	62.85	0.79
Fe/Zn	7.718	11.188	43.34	7.305	21.360	63.26	0.52
Fe/Mn	0.401	0.041	50.64	0.449	0.081	63.35	0.51
Zn/N	0.001	0.000*	18.71	0.001	0.000*	14.12	1.73^
Zn/P	0.019	0.350*	31.55	0.023	0.360*	26.57	0.97
Zn/K	0.001	0.000*	23.40	0.001	0.000*	24.51	0.73
Zn/Ca	0.002	0.000*	24.39	0.002	0.000*	27.55	0.71
Zn/Mg	0.020	0.840*	45.37	0.020	0.930*	49.27	0.90
Zn/S	0.017	0.540*	42.50	0.019	0.530*	38.11	1.02
Zn/Fe	0.152	0.003	37.96	0.167	0.004	35.83	0.92
Zn/Mn	0.054	4.020*	37.02	0.065	5.460*	36.15	0.74
Mn/N	0.026	0.620*	29.89	0.022	0.420*	29.02	1.49^
Mn/P	0.377	0.019	36.95	0.376	0.014	31.40	1.39^
Mn/K	0.025	0.550*	29.55	0.023	0.390*	26.99	1.42^
Mn/Ca	0.036	1.000*	28.05	0.031	0.630*	25.85	1.58^
Mn/Mg	0.405	0.039	48.68	0.324	0.028	52.10	1.37^
Mn/S	0.345	0.027	47.70	0.316	0.019	43.43	1.44^
Mn/Fe	3.038	1.649	42.27	2.797	1.362	41.72	1.20
Mn/Zn	20.881	52.114	34.57	17.491	39.115	35.76	1.33^

* x 10^{-4}

^ significant at 5 % level

Appendix III Relevant data for LYG DRIS norms for yield of berries in black pepper

(n = 307, Berry.yld. Mean =1.362421, SD = 0.6701971)

Ratio	Low yield group (A), n = 64			High yield group (B), n = 62			Var.ratio (SA/SB)
	Mean	Var.(SA)	CV %	Mean	Var.(SB)	CV %	
N	2.330	0.061	10.63	2.388	0.087	12.38	0.70
P	0.168	0.002	23.32	0.157	0.001	22.92	1.18
K	2.439	0.115	13.91	2.407	0.075	11.38	1.53^
Ca	1.765	0.131	20.52	1.825	0.121	19.04	1.09
Mg	0.177	0.012	63.09	0.197	0.014	60.35	0.88
S	0.186	0.004	35.59	0.214	0.006	34.70	0.79
Fe	0.023	1.350*	49.85	0.022	0.620*	36.09	2.19^
Zn	0.003	0.000*	19.59	0.003	0.000*	18.59	1.10
Mn	0.058	2.730*	28.26	0.063	2.180*	23.47	1.25
N/P	14.633	13.813	25.40	16.035	17.310	25.95	0.80
N/K	0.976	0.034	18.88	1.005	0.030	17.18	1.14
N/Ca	1.376	0.104	23.45	1.357	0.099	23.18	1.05
N/Mg	16.700	41.793	38.71	15.515	44.985	43.23	0.93
N/S	14.027	22.412	33.75	12.767	27.154	40.82	0.83
N/Fe	117.591	1809.707	36.18	120.480	1307.733	30.02	1.38
N/Zn	785.771	26532.189	20.73	801.977	39318.430	24.72	0.67
N/Mn	43.521	222.428	34.27	40.137	116.740	26.92	1.91
P/N	0.073	3.160*	24.48	0.067	3.630*	28.45	0.87
P/K	0.070	2.980*	24.77	0.066	2.450*	23.81	1.22
P/Ca	0.099	9.790*	31.61	0.089	8.230*	32.16	1.19
P/Mg	1.201	0.291	44.96	1.015	0.242	48.50	1.20
P/S	0.988	0.121	35.25	0.829	0.142	45.44	0.86
P/Fe	8.311	9.460	37.01	7.835	6.705	33.05	1.41
P/Zn	57.014	317.681	31.26	52.408	207.061	27.46	1.53^
P/Mn	3.091	1.259	36.29	2.623	0.783	33.73	1.61^
K/N	1.061	0.041	19.14	1.025	0.034	17.92	1.22
K/P	15.249	14.446	24.93	16.063	14.125	23.40	1.02
K/Ca	1.439	0.123	24.41	1.369	0.097	22.78	1.27
K/Mg	17.711	57.574	42.84	15.625	43.364	42.15	1.33
K/S	14.769	29.825	36.98	12.803	25.612	39.53	1.16
K/Fe	123.196	2032.363	36.59	120.876	1112.155	27.59	1.83^
K/Zn	830.371	47161.531	26.15	808.797	30747.801	21.68	1.53^
K/Mn	46.056	347.413	40.47	40.373	111.243	26.12	3.12^
Ca/N	0.765	0.030	22.71	0.778	0.035	23.97	0.87
Ca/P	11.069	10.724	29.58	12.223	12.413	28.82	0.86
Ca/K	0.736	0.031	23.86	0.771	0.035	24.39	0.87
Ca/Mg	12.789	34.549	45.96	11.790	30.477	46.82	1.13
Ca/S	10.639	16.078	37.69	9.661	17.538	43.35	0.92
Ca/Fe	89.050	1232.990	39.43	93.316	1264.207	38.10	0.98
Ca/Zn	600.179	34577.051	30.98	610.122	23092.000	24.91	1.50
Ca/Mn	32.374	115.396	33.18	30.674	95.535	31.86	1.21
Mg/N	0.076	0.002	62.40	0.084	0.003	62.40	0.82
Mg/P	1.099	0.498	64.19	1.304	0.607	59.77	0.82
Mg/K	0.075	0.002	65.54	0.084	0.003	67.97	0.73

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Mg/Ca	0.105	0.005	67.74	0.110	0.004	57.18	1.28
Mg/S	1.072	0.581	71.12	1.028	0.529	70.78	1.10
Mg/Fe	8.652	36.520	69.85	10.021	46.979	68.40	0.78
Mg/Zn	58.768	1314.300	61.69	66.303	1784.285	63.71	0.74
Mg/Mn	3.274	5.955	74.53	3.273	5.517	71.77	1.08
S/N	0.080	8.010*	35.33	0.091	0.001	38.25	0.66
S/P	1.134	0.148	33.95	1.414	0.283	37.65	0.52
S/K	0.078	9.320*	39.29	0.090	0.001	36.32	0.87
S/Ca	0.110	0.002	44.50	0.120	0.002	35.77	1.30
S/Mg	1.338	0.484	51.99	1.355	0.478	51.01	1.01
S/Fe	8.988	14.783	42.78	10.606	19.753	41.90	0.75
S/Zn	63.058	710.269	42.26	72.643	924.084	41.85	0.77
S/Mn	3.490	3.129	50.69	3.593	2.353	42.69	1.33
Fe/N	0.010	0.250*	50.02	0.009	0.110*	35.62	2.37^
Fe/P	0.144	0.006	52.86	0.143	0.003	35.54	2.24^
Fe/K	0.010	0.270*	53.59	0.009	0.110*	36.59	2.49^
Fe/Ca	0.014	0.570*	54.66	0.012	0.250*	40.04	2.31^
Fe/Mg	0.161	0.009	57.47	0.142	0.006	56.43	1.35
Fe/S	0.133	0.004	46.12	0.113	0.003	47.16	1.33
Fe/Zn	7.747	11.917	44.56	7.262	7.283	37.16	1.64^
Fe/Mn	0.425	0.051	53.35	0.360	0.017	36.14	3.04^
Zn/N	0.001	0.000*	19.25	0.001	0.000*	18.72	1.09
Zn/P	0.019	0.400*	32.85	0.021	0.310*	26.96	1.32
Zn/K	0.001	0.000*	25.50	0.001	0.000*	22.24	1.29
Zn/Ca	0.002	0.000*	28.08	0.002	0.000*	24.09	1.48
Zn/Mg	0.022	0.870*	42.72	0.020	0.860*	46.46	1.01
Zn/S	0.019	0.530*	39.28	0.017	0.580*	45.83	0.92
Zn/Fe	0.154	0.004	40.67	0.156	0.003	34.67	1.35
Zn/Mn	0.057	4.750*	38.05	0.052	2.260*	29.10	2.10^
Mn/N	0.025	0.570*	29.72	0.027	0.520*	27.03	1.08
Mn/P	0.362	0.014	33.01	0.417	0.015	29.23	0.96
Mn/K	0.024	0.610*	31.80	0.026	0.440*	25.21	1.37
Mn/Ca	0.034	0.950*	28.81	0.036	1.050*	28.83	0.91
Mn/Mg	0.412	0.032	43.56	0.398	0.028	42.17	1.15
Mn/S	0.355	0.026	45.84	0.335	0.024	46.40	1.09
Mn/Fe	2.908	1.649	44.16	3.171	1.477	38.33	1.12
Mn/Zn	19.809	49.221	35.42	21.094	40.382	30.13	1.22

* x 10^{-4}

^ significant at 5 % level

Appendix IV Relevant data for MYG DRIS norms for yield of berries in black pepper

(n = 450, Berry.yld. Mean = 3.679375, SD = 0.736997)

Ratio	Low yield group (A), n = 100			High yield group (B), n = 101			Var.ratio (SA/SB)
	Mean	Var.(SA)	CV %	Mean	Var.(SB)	CV %	
N	2.381	0.072	11.30	2.417	0.068	10.79	1.06
P	0.156	0.001	21.70	0.152	0.001	21.29	1.10
K	2.340	0.089	12.73	2.355	0.111	14.16	0.80
Ca	1.744	0.154	22.47	1.745	0.101	18.21	1.52^
Mg	0.211	0.016	59.22	0.223	0.016	56.75	0.97
S	0.208	0.007	39.38	0.210	0.005	34.53	1.28
Fe	0.023	1.150*	46.94	0.024	2.280*	61.58	0.51
Zn	0.003	0.000*	19.99	0.003	0.000*	18.19	1.05
Mn	0.058	3.130*	30.65	0.054	1.980*	26.04	1.58^
N/P	15.987	15.626	24.73	16.730	17.583	25.06	0.89
N/K	1.035	0.034	17.73	1.047	0.036	18.18	0.93
N/Ca	1.439	0.145	26.48	1.431	0.090	21.00	1.61^
N/Mg	14.772	47.952	46.88	14.185	47.469	48.57	1.01
N/S	13.359	31.380	41.93	12.939	22.268	36.47	1.41^
N/Fe	120.051	1670.278	34.04	121.080	2021.151	37.13	0.83
N/Zn	836.654	37253.980	23.07	787.159	26506.600	20.68	1.41^
N/Mn	45.527	269.193	36.04	47.869	212.496	30.45	1.27
P/N	0.066	2.510*	23.90	0.064	3.010*	27.15	0.83
P/K	0.067	2.390*	22.99	0.065	2.070*	22.10	1.16
P/Ca	0.093	5.950*	26.35	0.090	7.430*	30.14	0.80
P/Mg	0.979	0.259	51.93	0.884	0.186	48.85	1.39^
P/S	0.853	0.121	40.69	0.804	0.102	39.68	1.19
P/Fe	7.872	9.132	38.39	7.534	9.171	40.20	1.00
P/Zn	54.986	261.597	29.41	49.970	241.734	31.11	1.08
P/Mn	2.980	1.605	42.51	3.014	1.143	35.47	1.40^
K/N	0.997	0.032	17.85	0.987	0.032	18.24	0.98
K/P	15.613	11.876	22.07	16.080	11.546	21.13	1.03
K/Ca	1.405	0.117	24.30	1.407	0.140	26.62	0.83
K/Mg	14.431	44.139	46.04	14.023	52.988	51.91	0.83
K/S	13.009	26.964	39.91	12.533	20.181	35.84	1.34
K/Fe	117.857	1692.785	34.91	118.005	1960.353	37.52	0.86
K/Zn	825.219	39339.559	24.04	773.268	35932.719	24.51	1.09
K/Mn	44.352	214.048	32.99	46.711	216.672	31.51	0.99
Ca/N	0.744	0.039	26.66	0.729	0.023	20.60	1.75^
Ca/P	11.537	8.683	25.54	12.104	13.960	30.87	0.62
Ca/K	0.755	0.036	25.28	0.760	0.040	26.16	0.92
Ca/Mg	10.888	32.916	52.70	10.198	26.722	50.69	1.23
Ca/S	9.568	15.839	41.60	9.406	15.343	41.64	1.03
Ca/Fe	88.863	1403.232	42.15	88.058	1332.201	41.45	1.05
Ca/Zn	623.632	47113.328	34.81	570.794	22760.820	26.43	2.07^
Ca/Mn	33.143	230.777	45.84	34.150	92.742	28.20	2.49^
Mg/N	0.090	0.003	60.42	0.093	0.003	57.45	1.03
Mg/P	1.457	1.052	70.39	1.547	0.980	64.00	1.07

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Mg/K	0.091	0.003	60.36	0.098	0.004	62.02	0.82
Mg/Ca	0.128	0.007	64.36	0.132	0.006	59.44	1.10
Mg/S	1.180	0.771	74.44	1.166	0.528	62.34	1.46^
Mg/Fe	10.318	45.786	65.58	11.158	57.332	67.86	0.80
Mg/Zn	74.636	2254.065	63.61	72.952	2053.631	62.12	1.10
Mg/Mn	4.004	7.774	69.64	4.424	8.198	64.72	0.95
S/N	0.089	0.001	42.71	0.087	9.570*	35.36	1.51^
S/P	1.375	0.344	42.67	1.423	0.271	36.55	1.27
S/K	0.090	0.001	41.21	0.090	9.620*	34.49	1.44^
S/Ca	0.123	0.002	40.60	0.124	0.002	38.41	1.09
S/Mg	1.285	0.614	60.94	1.214	0.535	60.26	1.15
S/Fe	10.261	25.597	49.31	10.457	25.370	48.17	1.01
S/Zn	73.654	1121.032	45.46	70.282	1225.775	49.82	0.91
S/Mn	3.964	4.644	54.36	4.123	2.970	41.80	1.56^
Fe/N	0.010	0.210*	47.67	0.010	0.390*	61.16	0.55
Fe/P	0.154	0.007	53.47	0.166	0.011	61.85	0.64
Fe/K	0.010	0.200*	45.71	0.011	0.450*	63.21	0.45
Fe/Ca	0.014	0.620*	56.40	0.015	0.920*	65.65	0.67
Fe/Mg	0.137	0.007	61.27	0.144	0.014	81.42	0.52
Fe/S	0.123	0.004	50.41	0.133	0.013	84.45	0.30
Fe/Zn	8.248	24.071	59.48	8.059	25.650	62.85	0.94
Fe/Mn	0.425	0.043	48.98	0.487	0.113	69.13	0.38
Zn/N	0.001	0.000*	19.83	0.001	0.000*	16.53	1.31
Zn/P	0.020	0.380*	31.17	0.022	0.420*	29.52	0.92
Zn/K	0.001	0.000*	24.56	0.001	0.000*	24.56	0.88
Zn/Ca	0.002	0.000*	34.68	0.002	0.000*	25.93	1.67^
Zn/Mg	0.018	0.850*	50.35	0.018	0.840*	49.80	1.01
Zn/S	0.016	0.530*	44.02	0.017	0.490*	40.99	1.07
Zn/Fe	0.151	0.004	40.38	0.160	0.005	42.95	0.79
Zn/Mn	0.058	6.200*	43.29	0.063	4.790*	34.88	1.29
Mn/N	0.024	0.600*	31.57	0.023	0.360*	26.68	1.65^
Mn/P	0.385	0.018	34.66	0.374	0.018	35.98	0.98
Mn/K	0.025	0.550*	29.90	0.023	0.510*	30.39	1.09
Mn/Ca	0.034	1.060*	30.24	0.032	0.990*	31.31	1.07
Mn/Mg	0.353	0.035	53.16	0.316	0.029	54.22	1.20
Mn/S	0.319	0.025	49.40	0.289	0.016	44.38	1.51^
Mn/Fe	2.855	1.470	42.47	2.724	1.551	45.72	0.95
Mn/Zn	20.693	76.231	42.19	17.702	32.857	32.38	2.32^

* $\times 10^{-4}$

^ significant at 5 % level

Appendix V Relevant data for HYG DRIS norms for yield of berries in black pepper

(n = 343, Berry.yld. Mean = 6.685134, SD = 1.421593)

Ratio	Low yield group (A), n = 38			High yield group (B), n = 49			Var.ratio
	Mean	Var.(SA)	CV %	Mean	Var.(SB)	CV %	(SA/SB)
N	2.351	0.063	10.67	2.385	0.073	11.33	0.86
P	0.150	0.001	24.55	0.136	5.560*	17.31	2.42
K	2.241	0.109	14.73	2.276	0.122	15.32	0.90
Ca	1.747	0.139	21.36	1.753	0.139	21.26	1.00
Mg	0.212	0.015	57.36	0.228	0.020	61.71	0.74
S	0.220	0.006	36.29	0.161	0.003	33.02	2.27
Fe	0.022	1.190*	49.33	0.021	1.050*	49.45	1.14
Zn	0.003	0.000*	20.40	0.003	0.000*	17.88	1.16
Mn	0.051	1.560*	24.32	0.053	2.440*	29.62	0.64
N/P	16.650	19.304	26.39	17.912	10.362	17.97	1.86^
N/K	1.071	0.037	18.02	1.077	0.052	21.20	0.71
N/Ca	1.408	0.124	25.02	1.421	0.116	24.01	1.07
N/Mg	14.440	47.738	47.85	14.329	54.871	51.70	0.87
N/S	12.037	18.935	36.15	16.257	24.434	30.41	0.77
N/Fe	123.126	1741.203	33.89	129.163	1371.703	28.67	1.27
N/Zn	814.437	44341.570	25.86	761.989	13024.540	14.98	3.40^
N/Mn	49.049	233.600	31.16	49.950	343.875	37.13	0.68
P/N	0.065	3.490*	28.93	0.058	1.110*	18.29	3.14^
P/K	0.067	2.490*	23.45	0.061	1.320*	18.88	1.88^
P/Ca	0.089	8.240*	32.11	0.081	4.300*	25.62	1.91^
P/Mg	0.914	0.223	51.68	0.811	0.173	51.35	1.29
P/S	0.757	0.105	42.87	0.919	0.072	29.26	1.46
P/Fe	7.749	8.365	37.33	7.456	5.943	32.70	1.41
P/Zn	53.336	487.205	41.38	44.037	123.544	25.24	3.94^
P/Mn	3.223	2.867	52.55	2.803	0.907	33.98	3.16^
K/N	0.964	0.031	18.40	0.970	0.043	21.45	0.73
K/P	15.611	11.358	21.59	17.032	10.865	19.35	1.05
K/Ca	1.341	0.116	25.36	1.341	0.078	20.81	1.48
K/Mg	13.555	38.239	45.62	13.515	47.960	51.24	0.80
K/S	11.402	15.984	35.06	15.469	23.299	31.20	0.69
K/Fe	117.112	1624.563	34.42	125.144	1677.219	32.73	0.97
K/Zn	780.260	52148.000	29.27	742.003	41262.250	27.38	1.26
K/Mn	47.077	291.986	36.30	46.444	201.740	30.58	1.45
Ca/N	0.753	0.034	24.47	0.744	0.032	23.87	1.08
Ca/P	12.330	14.754	31.15	13.192	12.547	26.85	1.18
Ca/K	0.798	0.048	27.48	0.780	0.029	21.99	1.63
Ca/Mg	10.402	22.597	45.70	10.294	28.561	51.92	0.79
Ca/S	9.040	16.421	44.83	12.030	19.197	36.42	0.86
Ca/Fe	90.913	1177.642	37.75	95.339	1034.994	33.74	1.14
Ca/Zn	607.601	35637.762	31.07	570.398	30924.230	30.83	1.15
Ca/Mn	35.618	94.728	27.33	35.406	105.055	28.95	0.90
Mg/N	0.092	0.003	61.71	0.098	0.004	64.03	0.83
Mg/P	1.498	0.848	61.47	1.728	1.364	67.57	0.62
Mg/K	0.096	0.003	60.01	0.102	0.005	65.55	0.74

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Mg/Ca	0.124	0.006	60.61	0.133	0.007	60.71	0.87
Mg/S	1.082	0.502	65.47	1.576	1.380	74.52	0.36
Mg/Fe	10.952	59.869	70.65	12.231	71.004	68.89	0.84
Mg/Zn	73.262	2161.765	63.46	73.764	2268.874	64.57	0.95
Mg/Mn	4.474	8.723	66.02	4.536	7.576	60.68	1.15
S/N	0.094	0.001	36.03	0.068	4.420*	31.14	2.59^
S/P	1.517	0.322	37.41	1.186	0.133	30.74	2.42^
S/K	0.100	0.002	41.22	0.071	5.310*	32.31	3.17^
S/Ca	0.131	0.003	41.68	0.096	0.001	39.51	2.10^
S/Mg	1.335	0.602	58.08	0.952	0.330	60.38	1.82^
S/Fe	11.604	34.360	50.52	8.668	13.744	42.77	2.50^
S/Zn	77.965	1679.466	52.56	51.836	445.304	40.71	3.77^
S/Mn	4.582	4.244	44.96	3.267	1.899	42.18	2.23^
Fe/N	0.010	0.320*	58.34	0.009	0.160*	46.25	1.97^
Fe/P	0.155	0.006	51.42	0.158	0.009	60.39	0.70
Fe/K	0.010	0.340*	57.02	0.010	0.390*	65.30	0.87
Fe/Ca	0.013	0.590*	57.98	0.012	0.490*	56.59	1.21
Fe/Mg	0.131	0.006	60.87	0.119	0.006	62.75	1.14
Fe/S	0.116	0.005	63.70	0.140	0.006	55.20	0.91
Fe/Zn	7.805	22.979	61.42	6.587	8.650	44.65	2.66^
Fe/Mn	0.500	0.266	103.11	0.431	0.064	58.67	4.15^
Zn/N	0.001	0.000*	18.39	0.001	0.000*	12.62	1.97^
Zn/P	0.022	0.630*	36.56	0.024	0.300*	22.67	2.14^
Zn/K	0.001	0.000*	24.25	0.001	0.000*	26.39	0.76
Zn/Ca	0.002	0.000*	30.66	0.002	0.000*	28.66	1.02
Zn/Mg	0.018	0.690*	45.84	0.019	1.040*	53.54	0.66
Zn/S	0.016	0.430*	42.14	0.022	0.540*	33.61	0.81
Zn/Fe	0.158	0.004	39.15	0.173	0.003	33.07	1.17
Zn/Mn	0.063	5.560*	37.29	0.067	8.020*	42.00	0.69
Mn/N	0.022	0.360*	27.15	0.023	0.580*	33.86	0.62
Mn/P	0.368	0.019	37.23	0.392	0.014	29.78	1.38
Mn/K	0.023	0.430*	27.99	0.023	0.340*	25.31	1.24
Mn/Ca	0.030	0.610*	26.10	0.031	0.710*	27.66	0.86
Mn/Mg	0.316	0.028	53.19	0.306	0.030	56.40	0.95
Mn/S	0.266	0.016	47.66	0.354	0.017	36.96	0.94
Mn/Fe	2.696	1.047	37.96	2.885	1.549	43.14	0.68
Mn/Zn	17.928	41.492	35.93	17.298	46.332	39.35	0.90

* x. 10^{-4}

^ significant at 5 % level

Appendix VI Relevant data for DRIS norms for per cent content of oleoresin in black pepper

(n = 1100, Or. % Mean = 11.40982, SD = 2.009461)

Ratio	Low yield group (A), n = 176			High yield group (B), n = 229			Var.ratio
	Mean	Var.(SA)	CV %	Mean	Var.(SB)	CV %	(SA/SB)
N	2.346	0.072	11.40	2.382	0.067	10.84	1.07
P	0.159	0.001	22.02	0.154	0.001	21.70	1.11
K	2.388	0.093	12.78	2.372	0.104	13.59	0.90
Ca	1.794	0.118	19.18	1.726	0.125	20.46	0.95
Mg	0.200	0.014	59.22	0.211	0.014	56.97	0.97
S	0.205	0.007	41.27	0.204	0.007	40.52	1.05
Fe	0.020	0.700*	41.17	0.023	1.300*	50.20	0.54
Zn	0.003	0.000*	18.12	0.003	0.000*	19.19	0.85
Mn	0.058	2.640*	27.95	0.055	2.300*	27.36	1.15
N/P	15.402	13.207	23.59	16.228	14.435	23.41	0.91
N/K	0.999	0.031	17.58	1.024	0.035	18.17	0.89
N/Ca	1.359	0.101	23.39	1.434	0.100	22.05	1.01
N/Mg	15.048	44.110	44.13	14.651	46.475	46.53	0.95
N/S	13.394	28.519	39.87	13.486	27.002	38.53	1.06
N/Fe	128.317	1398.956	29.15	121.429	1643.662	33.39	0.85
N/Zn	799.292	22596.660	18.81	800.816	32138.109	22.39	0.70
N/Mn	44.037	229.197	34.38	46.426	218.437	31.83	1.05
P/N	0.069	2.710*	23.97	0.065	2.650*	24.96	1.02
P/K	0.067	2.180*	21.96	0.065	2.100*	22.16	1.04
P/Ca	0.091	5.910*	26.57	0.093	7.670*	29.91	0.77
P/Mg	1.026	0.258	49.57	0.945	0.222	49.84	1.17
P/S	0.892	0.130	40.50	0.850	0.106	38.35	1.23
P/Fe	8.708	9.014	34.48	7.822	8.435	37.13	1.07
P/Zn	54.568	230.998	27.85	52.101	275.902	31.88	0.84
P/Mn	2.977	1.410	39.88	2.986	1.226	37.09	1.15
K/N	1.031	0.031	17.11	1.010	0.035	18.62	0.88
K/P	15.583	11.322	21.59	16.037	12.204	21.78	0.93
K/Ca	1.376	0.087	21.47	1.432	0.120	24.21	0.73
K/Mg	15.255	44.532	43.75	14.585	46.387	46.70	0.96
K/S	13.627	30.246	40.36	13.419	28.315	39.66	1.07
K/Fe	131.047	1562.826	30.17	121.143	1750.870	34.54	0.89
K/Zn	820.809	35566.219	22.98	802.630	40700.699	25.14	0.87
K/Mn	44.571	235.487	34.43	45.911	194.932	30.41	1.21
Ca/N	0.777	0.035	24.18	0.732	0.028	22.66	1.28^
Ca/P	11.754	10.940	28.14	11.752	11.571	28.95	0.95
Ca/K	0.762	0.030	22.75	0.743	0.038	26.18	0.80
Ca/Mg	11.382	27.049	45.69	10.555	27.250	49.46	0.99
Ca/S	10.086	15.751	39.35	9.786	18.146	43.53	0.87
Ca/Fe	98.771	1187.415	34.89	87.896	1040.139	36.69	1.14
Ca/Zn	620.638	35053.172	30.17	584.704	31972.529	30.58	1.10
Ca/Mn	33.279	140.786	35.65	33.192	131.970	34.61	1.07
Mg/N	0.087	0.003	61.01	0.090	0.003	57.58	1.05
Mg/P	1.321	0.703	63.45	1.443	0.808	62.29	0.87

Contd xii

Mg/K	0.085	0.003	61.67	0.091	0.003	59.61	0.94
Mg/Ca	0.114	0.005	59.51	0.126	0.006	59.00	0.83
Mg/S	1.125	0.573	67.29	1.175	0.644	68.32	0.89
Mg/Fe	10.580	37.430	57.83	10.729	51.161	66.67	0.73
Mg/Zn	69.762	2111.560	65.87	71.157	2021.843	63.19	1.04
Mg/Mn	3.758	7.574	73.24	4.054	6.188	61.36	1.22
S/N	0.088	0.001	42.75	0.087	0.001	41.03	1.13
S/P	1.321	0.323	43.02	1.355	0.287	39.54	1.12
S/K	0.087	0.001	43.10	0.087	0.001	42.83	1.00
S/Ca	0.116	0.002	41.22	0.123	0.003	42.83	0.83
S/Mg	1.312	0.697	63.61	1.231	0.519	58.51	1.34^
S/Fe	10.953	24.400	45.10	10.368	28.677	51.65	0.85
S/Zn	70.748	1122.622	47.36	70.025	1314.604	51.78	0.85
S/Mn	3.789	3.508	49.44	3.941	3.490	47.41	1.01
Fe/N	0.009	0.120*	39.70	0.010	0.230*	50.01	0.52
Fe/P	0.133	0.004	49.69	0.155	0.007	55.32	0.60
Fe/K	0.009	0.160*	46.36	0.010	0.260*	52.22	0.62
Fe/Ca	0.012	0.360*	50.55	0.014	0.560*	54.81	0.63
Fe/Mg	0.127	0.005	58.22	0.138	0.008	66.51	0.64
Fe/S	0.113	0.003	51.34	0.128	0.008	67.44	0.44
Fe/Zn	6.897	7.499	39.70	7.613	14.603	50.19	0.51
Fe/Mn	0.377	0.041	53.71	0.438	0.054	53.12	0.76
Zn/N	0.001	0.000*	15.61	0.001	0.000*	17.29	0.80
Zn/P	0.020	0.300*	27.70	0.021	0.370*	29.01	0.81
Zn/K	0.001	0.000*	22.75	0.001	0.000*	24.16	0.83
Zn/Ca	0.002	0.000*	27.96	0.002	0.000*	28.14	0.87
Zn/Mg	0.020	0.860*	47.66	0.019	0.810*	47.89	1.06
Zn/S	0.017	0.540*	42.80	0.018	0.580*	43.37	0.94
Zn/Fe	0.165	0.003	33.63	0.157	0.004	37.89	0.87
Zn/Mn	0.057	5.140*	39.77	0.060	4.840*	36.55	1.06
Mn/N	0.025	0.620*	31.32	0.024	0.500*	29.96	1.24
Mn/P	0.380	0.017	34.44	0.376	0.016	33.44	1.08
Mn/K	0.024	0.460*	27.73	0.024	0.440*	27.98	1.06
Mn/Ca	0.033	1.010*	30.36	0.033	0.930*	29.26	1.09
Mn/Mg	0.367	0.031	47.81	0.338	0.032	53.17	0.95
Mn/S	0.329	0.025	48.28	0.314	0.023	48.16	1.11
Mn/Fe	3.158	1.443	38.03	2.825	1.463	42.82	0.99
Mn/Zn	20.137	55.029	36.84	18.807	45.718	35.95	1.20

* x 10-4

^ significant at 5 % level

Appendix VII Relevant data for DRIS norms for yield of oleoresin in black pepper

(n = 1100, Or.yld. Mean = 0.4586897, SD = 0.2896468)

Ratio	Low yield group (A), n = 180			High yield group (B), n = 165			Var.ratio (SA/SB)
	Mean	Var.(SA)	CV %	Mean	Var.(SB)	CV %	
N	2.335	0.084	12.43	2.399	0.055	9.77	1.53^
P	0.170	0.001	22.49	0.147	9.990*	21.48	1.46^
K	2.459	0.110	13.49	2.321	0.111	14.37	0.99
Ca	1.723	0.113	19.49	1.767	0.111	18.87	1.01
Mg	0.187	0.012	59.06	0.211	0.015	57.65	0.82
S	0.203	0.007	41.41	0.184	0.005	37.84	1.46^
Fe	0.022	0.850*	41.46	0.023	1.500*	53.23	0.57
Zn	0.003	0.003*	18.77	0.003	0.003*	18.14	1.01
Mn	0.060	2.660*	27.36	0.052	2.000*	26.98	1.33^
N/P	14.446	13.904	25.81	16.922	11.233	19.81	1.24
N/K	0.967	0.033	18.75	1.056	0.036	17.93	0.92
N/Ca	1.404	0.100	22.56	1.406	0.089	21.26	1.12
N/Mg	15.838	43.616	41.70	14.826	47.050	46.26	0.93
N/S	13.279	24.788	37.49	14.684	24.856	33.95	1.00
N/Fe	118.315	1558.876	33.37	122.470	1682.871	33.50	0.93
N/Zn	796.561	27946.189	20.99	795.833	26004.250	20.26	1.07
N/Mn	42.615	215.654	34.46	49.264	215.177	29.78	1.00
P/N	0.074	3.480*	25.29	0.062	1.770*	21.57	1.97^
P/K	0.070	2.640*	23.24	0.064	1.790*	20.88	1.47^
P/Ca	0.103	0.001	31.34	0.086	6.930*	30.42	1.49^
P/Mg	1.147	0.280	46.11	0.918	0.222	51.33	1.26
P/S	0.946	0.127	37.69	0.882	0.095	34.87	1.34^
P/Fe	8.566	9.945	36.82	7.455	7.529	36.81	1.32^
P/Zn	58.458	314.321	30.33	49.374	257.459	32.50	1.22
P/Mn	3.087	1.326	37.30	3.003	0.997	33.25	1.33^
K/N	1.070	0.039	18.46	0.978	0.033	18.56	1.18
K/P	15.136	13.430	24.21	16.286	11.112	20.47	1.21
K/Ca	1.479	0.114	22.84	1.358	0.093	22.45	1.23
K/Mg	16.817	53.650	43.56	14.413	48.915	48.53	1.10
K/S	14.015	29.838	38.98	14.212	26.932	36.52	1.11
K/Fe	124.840	1808.718	34.07	119.083	1836.319	35.99	0.98
K/Zn	845.030	41403.672	24.08	779.686	45439.219	27.34	0.91
K/Mn	44.975	267.721	36.38	47.331	186.875	28.88	1.43^
Ca/N	0.747	0.026	21.47	0.743	0.025	21.17	1.04
Ca/P	10.675	10.098	29.77	12.552	12.609	28.29	0.80
Ca/K	0.712	0.027	23.19	0.776	0.033	23.46	0.82
Ca/Mg	11.747	29.604	46.32	10.743	25.582	47.08	1.16
Ca/S	9.802	15.654	40.37	10.915	19.179	40.12	0.82
Ca/Fe	88.205	1185.971	39.04	90.382	1168.920	37.83	1.01
Ca/Zn	587.739	23023.000	25.82	593.573	33212.980	30.70	0.69

Contd xiv

Ca/Mn	31.041	112.071	34.10	35.704	99.208	27.90	1.13
Mg/N	0.081	0.002	60.88	0.089	0.003	59.24	0.88
Mg/P	1.137	0.441	58.46	1.517	0.969	64.87	0.46
Mg/K	0.078	0.002	62.93	0.094	0.003	61.90	0.72
Mg/Ca	0.112	0.005	61.97	0.121	0.005	57.50	1.00
Mg/S	1.059	0.601	73.18	1.314	0.934	73.55	0.64
Mg/Fe	9.342	39.332	67.13	10.623	50.225	66.71	0.78
Mg/Zn	63.764	1571.597	62.17	70.441	1965.902	62.94	0.80
Mg/Mn	3.356	5.094	67.26	4.226	6.147	58.67	0.83
S/N	0.088	0.001	42.16	0.077	8.230*	37.23	1.67^
S/P	1.224	0.259	41.59	1.266	0.178	33.29	1.46^
S/K	0.084	0.001	42.30	0.080	8.780*	36.90	1.43^
S/Ca	0.122	0.003	45.38	0.108	0.002	42.46	1.45^
S/Mg	1.369	0.635	58.21	1.142	0.484	60.93	1.31^
S/Fe	10.088	22.532	47.06	9.271	20.057	48.31	1.12
S/Zn	70.367	1257.274	50.39	62.120	886.794	47.94	1.42^
S/Mn	3.681	3.357	49.77	3.733	2.458	42.01	1.37^
Fe/N	0.010	0.160*	41.92	0.010	0.250*	52.00	0.66
Fe/P	0.137	0.004	47.13	0.161	0.008	54.93	0.54
Fe/K	0.009	0.170*	44.28	0.010	0.350*	58.06	0.48
Fe/Ca	0.014	0.420*	47.57	0.013	0.530*	54.18	0.79
Fe/Mg	0.148	0.006	54.04	0.138	0.008	64.04	0.83
Fe/S	0.125	0.004	52.36	0.139	0.008	65.25	0.52
Fe/Zn	7.577	9.325	40.30	7.726	22.923	61.97	0.41
Fe/Mn	0.400	0.037	48.11	0.472	0.084	61.42	0.44
Zn/N	0.001	0.000*	18.74	0.001	0.000*	15.28	1.53^
Zn/P	0.019	0.350*	31.67	0.022	0.350*	26.74	1.02
Zn/K	0.001	0.000*	23.94	0.001	0.000*	25.17	0.75
Zn/Ca	0.002	0.000*	24.48	0.002	0.000*	27.57	0.77
Zn/Mg	0.021	0.850*	44.91	0.019	0.840*	47.97	1.01
Zn/S	0.017	0.530*	41.97	0.019	0.530*	38.19	0.99
Zn/Fe	0.153	0.003	37.58	0.159	0.004	37.87	0.91
Zn/Mn	0.055	4.430*	38.07	0.064	5.410*	36.19	0.82
Mn/N	0.026	0.600*	29.82	0.022	0.390*	28.55	1.51^
Mn/P	0.369	0.019	36.96	0.368	0.014	32.08	1.33^
Mn/K	0.025	0.530*	29.63	0.023	0.400*	27.73	1.33^
Mn/Ca	0.035	1.050*	28.96	0.030	0.660*	27.03	1.58^
Mn/Mg	0.399	0.035	46.65	0.318	0.028	52.12	1.26
Mn/S	0.340	0.026	47.80	0.319	0.019	43.25	1.39^
Mn/Fe	2.993	1.488	40.76	2.684	1.395	44.01	1.06
Mn/Zn	20.487	48.656	34.05	17.603	40.493	36.15	1.20

* x 10^{-4}

^ significant at 5% level

DEVELOPMENT OF DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM (DRIS) IN BLACK PEPPER (*Piper nigrum* L.) IN RELATION TO YIELD AND QUALITY CHARACTERISTICS

By

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ABSTRACT OF A THESIS
Submitted in partial fulfilment
of the requirement for the degree

DOCTOR OF PHILOSOPHY

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ABSTRACT

An investigative analysis was undertaken during 1993-96 to work out an objective and effective technology for nutritional management of black pepper based on cause and effect relationship. A critical and comparative evaluation of the available methods in this connection, viz. critical level concept, DRIS concept and management based on soil test data, soil analysis was envisaged.

Approved standard procedures in estimating soil available and plant contents of nine elements, viz. N P K Ca Mg S Fe Zn and Mn and standard statistical methods were used in the study. A total of 1200 plants aged 14 years maintained at RARS, Ambalavayal were used as the test material in the study.

A non-genic variability in yield ranging from 0.16 to 13.8 kg $plant^{-1}$ was manifested by the crop which indicated that variability shall be bridged upwards through managerial techniques.

The range of available status of the elements in the soil analysis was very high. The lowest range of 0.9 to 4.5 ppm and the highest range of 144 to 1324 ppm were recorded by Zn and Ca, respectively. Soil pH ranged from 4.3 to 6.8. These were at the individual plant level. Foliar content as well as the range of the elements were much less and did not exactly related to soil available contents. Results also indicated that elements showed significant and specific interactions among themselves which varied with the elements. The pattern and magnitude of interactions at soil and plant level were different.

Evaluation of soil test data of the study against approved soil test 0 - 9 scale classification showed that rhizosphere environments belonged to medium rich to very rich class and that it could not explain the yield variability and hence could not be a reliable basis of nutritional management in fertile soil.

Examination of the foliar content of elements and their comparison with critical levels and ranges fixed by De Waard (1969) and Nybe (1986) respectively, showed that foliar content of all the elements in the study were above the critical levels which suggested that the critical level concept can not be an adequate guiding principle in nutritional management of black pepper. It may be adequate only in situations where any element becomes specifically critical. Its inadequacy may also be due to the positive and negative interactions of elements in the plant system as well as due to the fact that yield is the resultant of a process involving several elements simultaneously. Negative relationship of P in the early stages and yield level of 6.5 and <1 kg berries at 2.33 and 2.35 per cent level and similar observations confirmed the above contention.

DRIS concept was found to be more adaptable to explain the yield variability as it takes into account the content as well as interaction represented by ratios of every element with the others of the high yielding plants and tries to simulate them in low yielding plants. Results of the present study showed that by employing the DRIS concept and nutrient ratios, the content of every element can be identified at any time as absolutely deficient, relatively deficient, relatively sufficient, relatively excess and absolutely excess. This classification enabled to define the nature of recommendation as additive, deletive or ameliorative/ corrective. Testing of the classification of the population into discriminative low and high - yielding sub-populations employing mean ± one SD showed that the system may be perfect when the magnitude of yield limiting factors in the entire range of low yield is the same. Possibility of variability in yield limiting factors could be accommodated by sub-dividing the lower yield group into smaller groups as was done in deciles in the study. The results appeared to show that the per plant variability can be accommodated with reasonable accuracy in such a system of micro level yield group identification and application of DRIS norms to them. The unique advantage of the DRIS system to reach the maximum realizable yield through progressive diagnosis based on progressive experimentation shall be substituted by the decile classification proposed in the study to a very good extent.

Results of the present study showed that yield and quality factors are largely independent of each other and both can be improved by integrating the respective components even at the higher yield levels obtained in the present study. Analysis of inter-correlation matrix among elements at soil and plant level revealed the possibility of making specific recommendations to achieve progressive yield increases by working out quantity, intensity and rate of release characteristics of elements in the soil in relation to absorption.

Results in the present study showed that scientifically speaking the captions of DRIS indices or index values as " order of requirement " be modified as "order of limiting influences" - the former part of which is relative to metabolic deficiencies and the latter part to the metabolic excess.

Imbalance indices have to be viewed as qualitative and not quantitative indices as they are relative, primarily based on the relative deficiencies and excesses which in turn are dependent upon the relative contents and valencies of the ions.

The results of the study also revealed that with progressive increase in yield, causing higher nutrient removal, will make the soil not only more deficient but also increase the frequency of application of nutrients more.

The progressive increase in the number of limiting factors with yield improvement caused by higher rate of removal calls for more frequent monitoring and not treating the norm as static for a long period. The results of the experiment have brought to light a graded pattern of nutritional management for black pepper.

The primary limiting factors were found to be high native content of Fe and Mn which will have to be ameliorated. Secondly, at the low yield level the yield is limited by a relative deficiency of Zn caused by high P calling for a temporary skipping of P; supplemented with N and K which can take the yield upto 5 kg plant^{-1}. Excess S through the incidental application of prophylactic sprays of Bordeaux mixture and shortage of Ca and Mg appear to be the limiting factors at the higher yield class. Amelioration of acidity by supplying Ca + Mg carbonate, substitution of S containing fungicides and application of N and K shall constitute the recommendation, beyond which P may have to be applied.