FOLIAR ABSORPTION OF NITROGEN AND PHOSPHORUS BY CASHEW

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Agronomy
COLLEGE OF HORTICULTURE
Vellanikkara - Thrissur
Kerala

1994

DECLARATION

I hereby declare that the thesis entitled **Foliar Absorption of Nitrogen and Phosphorus by Cashew** is a bonafide record of research work done independently by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship, associateship or other similar title, of any other University or Society.

Vellanikkara

27-05-1994

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CERTIFICATE

Certified that this thesis **Foliar Absorption of Nitrogen and Phosphorus by Cashew** is a record of research work done independently by **Ms. Mini Abraham** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to her.

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ACKNOWLEDGEMENT

It gives me tremendous pleasure to express my deep sense of gratitude and indebtedness to **Dr. M. Abdul Salam**, Associate Professor, Department of Agronomy and Chairman of my advisory committee for his expert guidance, valuable suggestions, immense help, keen interest and constant encouragement throughout the course of this investigation and preparation of the thesis.

I express my sincere thanks to **Dr.E.Tajuddin**, Professor and Head, Department of Agronomy and member of my advisory committee for the timely help and valuable suggestion at different times of my study.

No word can truly represent my esteemed gratitude and indebtedness to **Dr. P.A. Wahid**, Professor (Radio Tracer), Radio Tracer Laboratory, Kerala Agricultural University and member of my advisory committee for his sustained interest, constant inspiration, constructive criticisms and everwilling help rendered throughout this investigation.

I thankfully acknowledge **Dr.N.N.Potty**, Professor, Department of Agronomy and member of my advisory committee for the timely help extended to me throughout this investigation.

With immense pleasure I express my heartful thanks to **Smt. N.V. Kamalam**, Associate Professor (Safety Officer), Radio Tracer Laboratory for the keen interest, sincere help and whole-hearted co-operation in carrying out the research work successfully.

My heartful thanks are expressed to **Dr.P.V.Balachandran**, Associate Professor, Radio Tracer Laboratory, for his timely help and suggestions at different periods of my work.

Let me place on record my sincere thanks to **Dr.S. Pathummal Beevi**, Associate Professor, Cashew Research Station, Madakkathara for the facilities rendered for the field studies during my thesis work.

I am grateful to **Dr. Luckins C. Babu**, Department of Plant Physiology, Forestry College and **Dr. K.V. Suresh Babu**, Department of Olericulture, College of Horticulture for their sincere help for the anatomical study.

My profound thanks are due to **Dr. M.I. Mohammed Ali**, **Dr.J.K. Sharma** and **Dr. M. Balasundaran**, Department of Plant Pathology and **Dr. Jose Kallarackal**, Department of Plant Physiology, KFRI, Peechi for their timely help and co-operation extended to me for doing my anatomical study.

I have no words to express my esteemed gratitude and indebtedness to **Dr. K.C. George**, Professor and Head, Department of Agricultural Statistics, College of Veterinary and Animal Sciences, Mannuthy and all the staff of the Department especially Smt. Santhabai and Mr. Prasad for their immense help and whole-hearted co-operation rendered for the statistical analysis of the data.

I am obliged to **Dr. P.S. John**, Associate Professor, Department of Agronomy for his sincere help and constant encouragement.

I thankfully acknowledge the help and co-operation rendered by the staff and all other members of Department of Agronomy.

I am thankful to M/s. Blaise Computer Consultancy, Mannuthy, for the neat typing of the manuscript.

I cannot wind up without expressing my overwhelming gratitude and love for all my friends who extended a helping hand at each and every juncture of my work and I utilise this opportunity to express my heartfelt thanks and indebtedness to all of them.

I remember the love and affection of my parents, brothers and sisters especially my late brother-in-law Dr. T.J. Johnson, which supported me at all stages, otherwise this venture would have remained a dream.

Above all, I bow my head before God Almighty whose blessings were always with me, enabling me to undertake this endeavour successfully.

MINI ABRAHAM

Dedicated to my
late grand parents

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF PLATES

Introduction

INTRODUCTION

Foliar nutrition is one of the most important methods of fertilizer application followed in many crops, as it provides greater nutrient use efficiency and quick response from crops. Also, this fertilization technique has the advantage of combining fertilizer nutrients with pesticide sprays to meet the twin objective of crop nutrition and crop protection.

Cashew (*Anacardium occidentale* L.) an evergreen tree is a crop of high commercial value. In India, it is grown in an area of 5.4 lakh hectares, of which 29 per cent is in Kerala (Anon, 1993). Research efforts made in the recent past could standardise the fertilizer requirement of this crop (Lefebvre, 1970; Reddy *et al*., 1981; Veeraraghavan *et al*., 1985 and Singh, 1991). Identification of efficient methods of fertilizer application is also as important as optimisation of the fertilizer dose. The nitrogen fertilizer is becoming increasingly costlier day by day. Application of nutrients through foliage is considered to be one of the efficient methods of crop nutrition as chances of loss of the foliar applied nutrients are less compared to those supplied through the soil.

Cashew is a crop that requires a definite pesticidal spray schedule for the control of one of its major pests. namely tea mosquito. As such there is greater scope for combining foliar application of nutrients like nitrogen and or phosphorus with these pesticide sprays in this crop. Several researchers have attempted to study the effect of foliar application of nitrogen and phosphorus in cashew (Nair et al., 1972; Ankaiah, 1980 and Reddy, 1993). All these reports revealed that foliar application of nitrogen as urea and phosphorus as orthophosphoric acid did not influence nut yield in cashew, although certain growth parameters like height and girth had been favourably influenced. These results led us to find out the reasons for the shyness of this crop in responding to foliar applied nutrients.

Several plant characteristics and environmental factors can influence the absorption of foliar applied nutrients. Among the plant characteristics, leaf age, leaf surface, cuticle thickness, stomatal index, physiological phase of the plant etc. can play a vital role in the foliar absorption of nutrients (Jyung et al., 1965; Bukovac et al., 1979 and Flore and Bukovac, 1982). Similarly environmental factors such as atmospheric temperature, relative humidity etc. can also influence foliar absorption (Lidster et al., 1977 and Flore and Bukovac, 1982). Other factors such as time of application in a day, season of application in a year, duration allowed for absorption, inclusion of a surfactant in the spray etc. (Cook and Boynton, 1952; Yogarantnam and Greenham, 1982 and Reddy, 1993) may also alter the absorption of foliar applied nutrients.

No effort has been made so far to identify the factors affecting the absorption of foliar applied nutrients in cashew. Hence a series of lab and field studies were under taken at the College of Horticulture, Kerala Agricultural University, Vellanikkara with the following objectives.

To develop a method to quantify the foliar absorption of nitrogen and phosphorus by cashew.

To study the influence of crop factors such as leaf age and leaf surface on foliar absorption of nitrogen and phosphorus by cashew.

To study the foliar absorption of nitrogen and phosphorus in relation to time of application in a day and month of application in a year.

To study the foliar absorption of nitrogen and phosphorus in relation to different durations of absorption.

To study the effect of different concentrations of a surfactant namely teepol on foliar absorption of nitrogen and phosphorus.

To study the root absorption of ^{14}C-urea and ^{32}P by cashew seedlings and

To study the leaf anatomy (cuticle thickness, stomatal index) of cashew in relation to leaf age and leaf surface.

Review of Literature

REVIEW OF LITERATURE

A brief review on the effect of foliar applied nutrients in cashew and in other crops are presented below. Literature regarding the methods for studying foliar absorption of nutrients are also presented.

1. Method for studying foliar absorption of nutrients

Cook and Boynton (1952).standardised a leaf washing technique to quantify the absorption of foliar applied urea by 'Mc Intosh' apple leaves. At the end of absorption time, the leaves were detached, washed individually with low pressure jet of distilled water containing a wetting agent. The wastings were collected and analysed for total nitrogen. A second washing was also attempted to determine the efficiency of the leaf washing technique and found that the recovery by this second washing was negligible. The authors therefore concluded that any nitrogen which was not removed by a single washing can be considered as being absorbed.

Freiberg and Payne (1957) studied the mechanism of foliar absorption of ^{14}C-urea in banana by adopting a leaf washing technique. The treated leaf discs and leaf sections were placed in 50 ml of distilled water and shaken vigorously for one minute. The decanted washing solution was analysed to determine the amount of urea still remaining on the leaf surface and the absorbed amount by the leaf was determined by the difference method.

In a study on the foliar absorption of phosphorus (^{32}P labeled NaH_2PO_4) in sunflower (Wilson and Mckell, 1961), the treated leaves were subjected to a leaf washing technique. The treated leaf was washed with 0.01 N HCl containing 0.01 per cent sodium heptadecyl sulfate. Adequacy of the number of washing was checked by collecting the wash solution from the treated leaves in four successive 25 ml washings. The percentage of phosphorus in the four successive washings of the leaf was 99.25, 0.66, 0.06 and 0.03. Therefore, it was decided that a single washing was enough to quantify the amount of phosphorus absorbed by the plant.

Jyung and Wittwer (1964) studied the mechanism of foliar absorption of phosphate (^{32}P) and rubidium (^{86}Rb) in bean leaves by developing a leaf immersion and leaf washing technique. The treated leaves were washed by immersing it momentarily six times for 50 seconds each in three successive 50 ml quantity of distilled water. The unabsorbed residues remained on the surface of the treated leaf was removed by this washing procedure. The amount absorbed by the leaf was determined by the difference method.

Ahlgren and Sudia (1967) studied the mechanism of foliar absorption of phosphate (^{32}P) in soybean by following a leaf washing technique.

The foliar absorption of phosphate (^{32}P) by maize leaves was studied by Datta and Vyas (1967) by following a leaf washing technique with distilled water to exclude the unabsorbed fraction sticking on the surface. Retention of the labeled nutrient in the plant material after washing was considered equivalent to absorption.

Shim *et al*. (1972) studied the utilization of post harvest urea sprays by senescing apple leaves. The leaf washing technique followed were washing of the treated leaves in one litre of 0.1 N HCl + 0.1 per cent Tween - 80 for 30 seconds and rinsing with deionized water for 30 seconds. The urea absorption was determined by taking the difference between the initial amount of urea applied and the amount present in the leaf washing.

From the above review it can be seen that a sequential leaf washing technique is a commonly used method by researchers to quantity the foliar absorption of nutrients.

2. Foliar nutrition in cashew

At College of Agriculture, Vellayani, Nair *et al*. (1972) studied the response of cashew to the foliar application of nitrogen (224 g tree^{-1}) as urea. It was found that there was no significant increase in nut yield over the control due to foliar application. In an experiment conducted under the All India Co-ordinated Spices and Cashewnut Improvement Project, during 1972 at Government Cashew

Plantation, Kasaragod, it was found that urea spray (10 and 15 per cent) along with endosulfan (0.1 per cent) did not increase the nut yield in cashew (Anon., 1975).

In a similar experiment conducted at Vridhachalam, the effect of foliar application of urea on nut yield was again found to be absent (Anon., 1980). Ankaiah (1980) studied the effect of foliar fertilization of nitrogen on cashew at the Agricultural College, Bapatla and reported that foliar application had no advantage over soil application. Reddy (1993) studied the response of cashew to foliar application of nitrogen and phosphorus at Cashew Research Station, Kavali, Andhra Pradesh and found that the number of apples and nuts per tree did not increase due to foliar application. However, combined application of urea and orthophosphoric acid was useful than individual sprays in increasing yield. Salam and Kamalam (1993) using ^{14}C-labeled urea established that urea is absorbed by cashew seedlings through leaf as well as through root, in the molecular form.

From the review presented so far, it can be seen that cashew seldom responds to foliar application of nutrients. The influence of environmental and plant factors might be responsible for this dismal trend. The main objective of the present project is to identify the factors affecting foliar absorption in cashew.

3. Foliar nutrition in other crops

Possibility of enhancing the use efficiency of major nutrients through foliar sprays on perennial fruit crops had been studied in several crops. The yield of grape vine was not enhanced by four urea sprays applied in three years (Fleming and Alderfer, 1949). Fisher and Cook (1950) observed that under favourable condition , spraying apple trees three times with urea during the growing season produced higher yield than soil application of an equivalent amount of nitrogen. Bullock and Benson (1952), with trials of foliar sprays on peach trees, concluded that foliar fertilization did not increase the yield. Venkataramani (1957) reported that foilar application of potassium in tea had given significant increase in yields compared to untreated plants.

Several workers reported increased growth, yield and quality of fruits by foliar application of urea in guava (Arora and Singh, 1970 and Doraipandian and Shanmugavelu,1972), mango (Samra et al., 1977 and Rajput and Tiwari,1979), citrus (Singh, 1975 and Govind and Prasad, 1976) and apple (Rasmussen, 1966 and Neilsen et al., 1993).

Foliar fertilization of phosphorus was found to increase the yield in guava and mango (Singh and Rajput, 1977 and Reddy and Majumdar, 1983) and the vigour and growth in apple trees (Neilsen *et al*., 1993).

Ahenkorah *et al*. (1987) studied the effect of foliar fertilization of NPK (1 per cent of urea, muriate of potash and superphosphate) on cocoa seedlings and observed increased vigour and growth of seedlings. Devarajan *et al*. (1991) studied the effect of foliar nutrition of N, P and K on coffee plant and found that three times foliar application (1 per cent of urea, superphosaphate and muriate of potash) as a supplement to soil application, increased the coffee berry yield and quality.

In a study conducted by Peeran *et al*. (1970) in ground nut, observed that application of half nitrogen before sowing and the reminder as a foliar spray in two split doses, increased the seed yield, compared to soil application of entire quantity. Combined application of nitrogen and phosphorus partly through soil and partly through foliage at vegetative phase and at flowering in black gram gave better growth and yield (Elizebath *et al*., 1983).

From the review presented above, it is clear that foliar nutrition is advantageous to many crops.

4. Factors affecting foliar absorption

4.1. Plant characters

Several factors related to plant and environment can influence the foliar absorption of nutrients. A brief review on the influence of plant characters, environmental factors and other factors on the foliar absorption of nutrients by crops is presented below.

4.1.1. Leaf age

Many researchers reported inhibition of absorption with increase in leaf age in apple (Cook and Boynton, 1952), coffee, cocoa and banana (Cain, 1956), peach (Bukovac, 1965), *Phaseolus vulgaris* (Sargent and Blackman, 1970 and 1972) and pear (Greene and Bukovac, 1971). Cook and Boynton (1952) showed that terminal leaves of 'Mc Intosh' apple absorbed almost twice as much urea as that absorbed by basal leaves within two hours period.

Absorption of phosphorus by young apple leaves was greater than that of the older leaves (Fisher and Walker, 1955). Ahlgren and Sudia (1967) found that immature leaflets of soybean absorbed more phosphate than mature leaflets. Similar results were reported by Datta and Vyas (1967) in maize.

Nagarajah (1978) found reduction in the stomatal aperture with increase in the age of cotton leaves. Increase in the epicuticular wax in peach due to increase in leaf age was reported by Bukovac et al. (1979).

A field study on variation in foliar absorption of urea with age of leaf in cashew showed that three week old leaves absorbed more urea than aged leaves (Ankaiah and Rao, 1984).

In contrast to the above, Impey and Jones (1960) reported that young leaves of citrus did not absorb urea as rapidly as mature leaves.

From the above review, it can be seen that foliar absorption is generally more with young leaves and it decreases with age.

4.1.2. Leaf surface

Absorption of urea by apple leaves differed with leaf surface and it was higher through the lower surface compared to the upper one (Boynton et al., 1953). Several other workers reported that the lower surface of leaves of many crops absorb urea more rapidly than upper surface in apple (Ginsberg, 1930; Cook and Boynton, 1952; Rodney, 1952; Goodman and Addy, 1962) and peach (Bukovac et al., 1979). The increased absorption by the lower surface was due to the occurrence of more stomata and thus greater absorption through the guard cells on the lower surface (Sargent and Blackman, 1962; Franke, 1964; Jyung *et al.*, 1965; Wittwer *et al.*, 1967; Norris and Bukovac, 1968; Franke, 1969; Leece, 1978). Cuticles on the lower surface of leaves are generally thinner than those on the upper surface and hence the rate of absorption was more through the lower surface (Jyung *et al.*, 1965). The thicker cuticle on the upper surface was a major barrier to the penetration of nutrients even in very young leaves of *Phaseolus vulgaris* (Sargent and Blackman, 1970).

Flore and Bukovac (1982) studied the foliar absorption of ^{14}C-labeled ethephon in cherry in relation to leaf surface and surfactant. It was found that the absorption was greater through the lower surface compared to the upper one.

From the above review, it is clear that foliar absorption is more through the lower surface than the upper one in many crops.

4.1.3. Cuticle

The epicuticular wax, the outermost and most hydrophobic component of the cuticle is the prime barrier to foliar penetration (Darlington and Circulis, 1963; Denna, 1970 and Martin and Juniper, 1970 and Leece, 1978).

Electro-micrograph study of surface wax extrusion from the cuticle in *Brassica* sp. and *Musa* sp. revealed that as the leaf age increased, extrusion of surface wax increased and the young leaf had no wax (Ludwig et al. 1954). The cuticle on the lower surface of leaves of tobacco, bean and tomato was thinner than that on the upper surface (Jyung et al., 1965).

The epicuticular wax which is present on the outer surface of cuticle increased with leaf development and the two leaf surfaces, differed markedly in their structure and chemical composition of their epicuticular wax (Bukovac et al., 1979).

4.1.4. Stomata

In plants such as citrus (Ginsberg, 1930), apple (Rodney, 1952), plum (Leece, 1978), peach (Bukovac, et al., 1979), cherry (Flore and Bukovac, 1982), cocoa and rubber (Senagomes and Kozlowski, 1988) and cashew (Kallarackal and Somen, 1992) stomata were present only on the lower surface of leaf.

Freiberg and Payne (1957) reported that, lower leaf surface of banana contained three to four times more stomata than the upper surface and the urea absorption was also more through the lower surface. Sands and Bachelard (1973) found that lower surface of eucalyptus leaves contain more stomata than upper surface and the absorption of picloram increased with decrease in stomatal resistance.

Stomata play a vital role in absorption of foliage applied chemical in <u>Pinus radiata</u> (Franich <u>et al</u>., 1977). They also observed that the number of stomata decreased with increase in the age of trees.

Guard cells play a special role in foliar absorption and these cells were equipped with more ectodesmata than other areas of the leaf (Nagarajah, 1978). Most plant species had 50-300 stomata mm^{-2} of leaf surface and account for around 1.5 to 3 per cent of the leaf surface (Forbes and Watson, 1992).

4.2. **Environmental factors**

Environment may affect foliar absorption of nutrients by influencing physiological processes that are linked with the active uptake mechanism (Flore and Bukovac, 1982).

4.2.1. Temperature

Westwood and Batjer (1958) reported that higher the drying temperature and longer the time required to dry the sprays, greater the NAA and DNOC (Dinitro-ortho-cresol) absorption by apple leaves.

According to Forbes and Watson (1992), in most plants, the size of the stomatal pore increased with temperature upto 30°C.

4.2.2. Light

Light enhanced absorption of phosphate and rubidium in bean leaves (Jyung and Wittwer, 1964), potassium in corn leaves (Rains, 1968) and urea by apple leaves (Shim et al., 1972). The probable reason for this enhanced absorption was that, absorption of mineral nutrients through stomata was an energy dependent process and this energy was supplied by photophosphorylation. Ahlgren and Sudia (1967) reported that light increased the absorption and translocation of phosphate by soybean leaves. Stomata generally open in the light at least in well-watered plants and close in the dark, although plants show a wide range of diurnal patterns of stomatal activity (Forbes and Watson, 1992).

Investigation by Gustafson (1956) indicated an increase in foliar absorption of ^{60}Co by beans and cucumber seedlings with an increase in temperature and light intensity. According to Jyung and Wittwer (1964) increase in light and temperature increased absorption of phosphate and rubidium by bean leaves. In the light, uptake of chloride ions increased with temperature in Phaseolus vulgaris (Sargent and Blackman, 1970). Increase in temperature and light resulted in a dramatic increase in ethepon absorption (Flore and Bukovac, 1982).

4.2.3. Relative humidity

High humidity increased the absorption of foliar applied 2,4-D (Pallas, 1958) urea (Volk and Mc Auliff, 1954) and maleic hydrazide (Zukel et al., 1956). Absorption and translocation of chemicals by cotton leaves were greatly increased under conditions of high humidity (Clor et al., 1963). Exposure of the outer side of the epidermis to dry air caused the stomata to close while moist air caused the stomata to open (Lange et al., 1971). Lidster et al. (1977) found that higher (94 per cent) as well as lower (80 or 75 per cent) relative humidity decreased the rate of Ca^{2+} uptake and the optimum absorption was found to be at 87 per cent relative humidity. In many plants stomata begin to open before dawn if the night is long enough and start to close towards the end of the day even if the light intensity is kept constant (Kappen and Haeger, 1991).

4.2.4. Effect of season

In cashew, an investigation was conducted by Reddy (1993) to find out the seasonal influence on the efficiency of foliar applied nitrogen (4 per cent urea) and phosphorus (0.5 per cent orthophosphoric acid). The sprays were given during September, October and March when the fruit bud initiation, differentiation and flowering/fruiting took place. Number of apples and nuts per tree was not affected applied urea was found to be more when foliar spray was done in the month of March coinciding with flowering/fruiting period.

4.3. Other factors

4.3.1. Duration of absorption

Absorption of phosphate by tomato leaves increased with time (Arnon et al., 1940). Absorption rate was rapid for the first ten hours and decreased thereafter. According to Cook and Boynton (1952), absorption of urea by lower leaf surface was much more rapid than by upper surface over a short period of time (8 hours). But over a three day period, upper leaf surface continued to absorb urea at a steadier rate than the lower one.

Works done by Impey and Jones (1960) on the rate of absorption of urea by intact leaves of Washington Navel orange showed that urea was absorbed rapidly by the lower surface of leaves over a two hour period. Thereafter, absorption proceeded at a slow but continuous rate and within 30 hours virtually all of the applied urea had been absorbed.

Foliar absorption is a direct function of time over a 24 hour absorption period (Wilson and Mckell, 1961; Jyung and Wittwer, 1964 and Wittwer *et al.*, 1965). Results of the work done by Bukovac (1965) indicated that initial absorption of chlorophenoxy-α-propionic acid by peach leaves (upper and lower surface) was rapid for the first 12 to 24 hours and then progressively slow approaching a plateau.

4.3.2. Effect of surfactants

There are several reports regarding the effect of surfactants on the absorption of foliage applied chemicals. Work done by Cook and Boynton (1952) showed that surfactants such as Tween-80 (0.1 per cent) and Tween-20 (0.01 per cent) doubled the absorption rate of urea by apple leaves. Absorption of naphthalene acetic acid (NAA) was increased in apple by the addition of Tween-20 in the spray solution (Westwood and Batjer, 1958 and Edgerton and Haeseler, 1959).

Stomatal penetration by aqueous solution into the leaves of Zebrina, pear and apricot occurred rapidly if an efficient surfactant was used at the proper concentration (Dybing and Currier, 1961). They also reported that surfactants varied in their ability to promote stomatal entry and the concentration of surfactant necessary for stomatal penetration varied with the species.

Foliar absorption is increased by means of detergents, which help to bring the solution on to larger surface area from where they will be absorbed into the cells (Franke, 1964). Use of detergents and wetting agents facilitated the entry of solutes into the stomatal cavity (Wittwer, et al., 1965). Coble et al. (1970) evaluated the foliar absorption of 2,4-D by honey vine milk weed and found that absorption of 2,4-D was increased to seven to eight fold by using a surfactant with spray.

Weinbaum and Neumann (1977) showed that employment of a surfactant (L-77) enhanced the rate of absorption and translocation of nitrate from leaves of french prune. Flore and Bukovac (1982) reported that addition of a surfactant X-77 (mixture of alkylaryl - poly oxyethylene glycols, free fatty acids and isopropanol) increased absorption of ethephon.

In contrast to the above findings, Swanson and Whitney (1953) reported that inclusion of surface active adjuvents Tween-80 and Tween-20 retarded the ^{32}P absorption by bean leaves. Norris (1973) observed that a non-ionic surfactant HLB-167 at concentrations ranging from 0.05 to 1.0 per cent (V/V) did not alter the penetration of 2,4-D through the enzymatically isolated astomatous upper cuticle of pear leaves. The use of surfactants such as aerosol-OT, triton x-100 and monflor-51 along with iron sprays were not found to be advantageous in citrus (Walliham *et al*., 1964; Neumann and Prinz, 1974).

From the review presented above, it is clear that plant characters such as leaf age, leaf surface, cuticle and stomata, environmental factors such as the temperature, light, relative humidity and season of a year and other factors such as duration allowed for absorption and inclusion of a surfactant in the spray solution play a dominant role in deciding the extent of absorption of the foliar applied nutrients.

5. Distribution of foliar absorbed nutrients in the plant

Translocation and distribution of nutrients are more towards younger leaves than older leaves (Biddulph, 1951 and Ahlgren and Sudia, 1967). According to Koontz and Biddulph (1957) those leaves nearest to the root translocate major part of nutrients to the root, whereas the leaves at the top of the stem translocate predominantly to the apical region. In maize, it was seen that the foliar applied phosphorus moved upwards to the young developing leaves, or downward to the roots depending on the relative proximity of the sink (Biddulph *et al*., 1958). Transportation of absorbed ^{32}P towards the immature leaflets which are active 'sinks' for assimilate and minerals had been observed by Ahlgren and

Sudia (1967) in soybean and Datta and Vyas (1967) in maize. Cain (1956) reported that in banana, coffee and cocoa plants, within 24 hours, about 92 per cent, 70 per cent and 18 per cent of leaf absorbed urea nitrogen was exported from the absorbing leaves respectively. About 50 per cent of the urea nitrogen absorbed by apple leaves was translocated within 24 hours (Boynton et al., 1953).

The high mobility of spray applied phosphorus to the leaves or bark of apple and cherry trees had been reported by Eggert et al. (1952), Bukovac and Wittwer (1959) and Yogaratnam and Greenham (1982). Foliar absorbed phosphorus in apple started to migrate from leaves within the first 24 hours following foliar treatment and continued for at least six days (Yogaratnam et al., 1981).

It is clear from the above that foliar absorbed nutrients are translocated to the other plant parts within 24 hours of application and the translocation process continue.

6. Root absorption

Biddulph (1940) studied the absorption and movement of radio phosphorus by the excised roots of bean plants and observed an increased absorption with time. The movement of radio phosphorus in the bean plant was rapid and followed calcium and chlorine by roots of maize and found that an increased uptake of calcium and chloride ions with duration of absorption.

Uptake of ^{15}N-labeled NH_4^+ in excised roots of wheat increased with time (Picciurro et al., 1967). Initial rate of absorption was rapid and the rate decreased with time. In a study on the radioactive strontium uptake by excised barley roots, Kramer (1978) reported that the relationship between time and ion uptake was curvilinear, showing rapid uptake for a short time followed by a long period of slower uptake. Rice plants absorbed molecular urea through roots (Saraswathi et al., 1991). Salam and Kamalam (1993) reported molecular absorption of urea by cashew roots and leaves.

From the above review, it is clear that absorption of nutrients by plant roots increases with time with a rapid initial uptake followed by a long slower uptake. It was also established that rice and cashew roots absorbed urea in the molecular form itself.

Materials and Methods

MATERIALS AND METHODS

The present study was conducted at the Radio Tracer Laboratory, College of Horticulture, Kerala Agricultural University, Vellanikkara and Cashew Research Station, Madakkathara. The main objective of the investigation was to study the foliar absorption of nitrogen and phosphorus by cashew and the factors affecting foliar absorption. For this purpose, a series of laboratory and field experiments were conducted for a period of one year during 1993-94.

The studies undertaken were as follows:

Part I - Development of a method to study the absorption of foliar applied ^{14}C-urea and ^{32}P

Part II - Factors affecting foliar absorption

a) Foliar absorption of ^{14}C-urea by cashew seedlings in relation to leaf position and leaf surface.

b) Foliar absorption of ^{32}P by cashew seedlings in relation to leaf position and leaf surface.

c) Foliar absorption of ^{14}C-urea by cashew seedlings in relation to leaf age.

d) Foliar absorption of ^{32}P by cashew seedlings in relation to leaf age.

e) Foliar absorption of ^{14}C-urea in relation to duration of absorption and leaf surface.

f) Foliar absorption of ^{32}P in relation to duration of absorption and leaf surface.

g) Diurnal variation in the foliar absorption of ^{14}C -urea.

h) Diurnal variation in the foliar absorption of ^{32}P.

i) Effect of teepol on foliar absorption of ^{14}C-urea.

j) Effect of teepol on foliar absorption of ^{32}P.

k) Monthly variation on foliar absorption of ^{14}C-urea in relation to leaf age and leaf surface.

l) Monthly variation on foliar absorption of ^{32}P in relation to leaf age and leaf surface.

Part III- Root absorption of ^{14}C urea and ^{32}P by cashew seedlings

Part IV - Studies on leaf anatomy in relation to foliar absorption

Part V - Canopy analysis in cashew

The experimental site is located at 10° 32'N latitude and 76°10'E longitude at an altitude of 22.5 m above mean sea level.

The area enjoys a warm humid tropical climate, with 260.5 cm rainfall per annum and mean relative humidity of 73.83 per cent. The maximum and minimum temperatures ranged from 28.5°C to 35.4°C and 21.1°C to 27.8°C respectively. The weather conditions during the experimental period are given in Fig. 1.

MATERIALS

The studies were conducted both on three month old cashew seedlings in glass house and on six year old cashew trees at Cashew Research Station, Madakkathara.

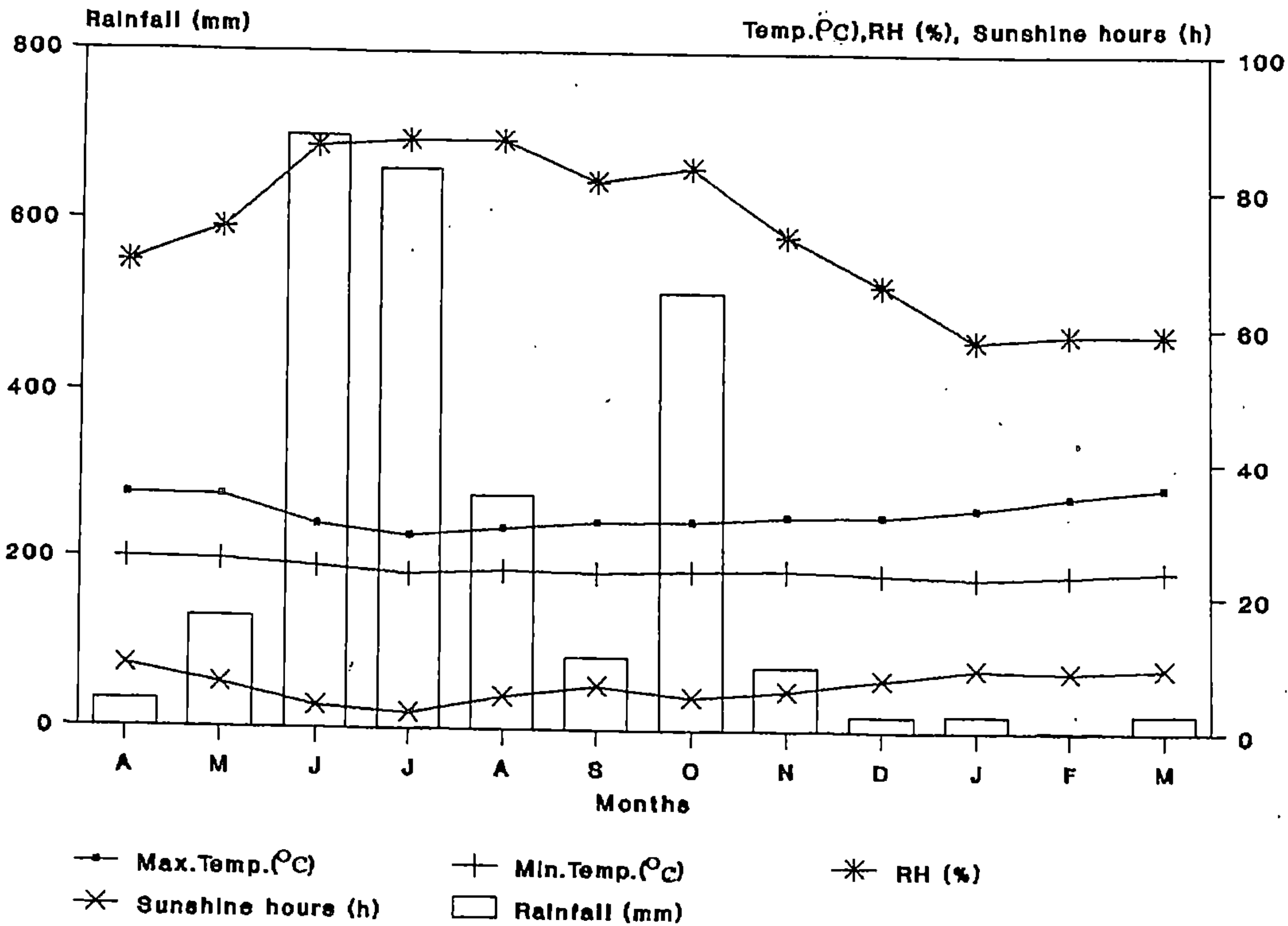
a. Preparation of seedlings

Three month old cashew seedlings (var. Anakkayam-1) were raised in the glass house in polythene bags containing a mixture of garden soil, sand and cowdung (in the ratio of 1:1:1) and used for glass house experiments.

b. History of experimental trees

For field studies, six year old cashew trees (var. Anakkayam-1) planted with softwood grafts at Cashew Research Station, Madakkathara on 15th June, 1987 were used. The

Fig.1 Weather during experimental period



spacing of the trees was 7.5 m x 7.5 m. The trees were raised rainfed and maintained well as per the package of practices recommendations of Kerala Agricultural University (KAU, 1989).

c. Procurement of ^{14}C-urea and ^{32}P

^{14}C-urea (specific activity of 53.15 m Ci/m mol) and ^{32}P were obtained from the Board of Radiation and Isotope Technology, Bombay.

METHODS

^{14}C-assay

a. Leaf washings

The leaf washings collected for radioassay were alkaline. To avoid chemiluminescence, the washings were acidified with one drop of 6N HCl. From the acidified solution, one ml was taken and added in a scintillation vial containing 15 ml of dioxan based liquid scintillator (4 g PPO, 0.2 g POPOP, 60 g naphthalene, 100 ml methanol and 20 ml ethylene glycol diluted to 1000 ml with dioxan). The radioactivity was determined by liquid scintillation counting technique in a microprocessor-controlled liquid scintillation system (Pharmacia LKB Wallac OY, Finland). The radioactivity in the washing was recorded as cpm after making background correction. The difference in radioactivity between the applied dose and the radioactivity recorded in the leaf washings (unabsorbed portion) was taken as the fraction absorbed by the leaf.

b. Plant material

For the determination of ^{14}C activity in the plant sample, biological sample oxidizer was used. The method involved dry combustion of 0.2 g of the oven-dried powdered sample in biological sample oxidizer (0 X 500 R.J. Harvey Instrument Corporation, New Jersey) and the $^{14}CO_2$ evolved was trapped in 15 ml Cocktail solution (M/s Harvey Carbon 14 Cocktail) in a scintillation vial. The radioactivity trapped was determined in a liquid scintillation system (Pharmacia LKB Wallac OY, Finland). The radioactivity was recorded as cpm after making background correction.

^{32}P - assay

a. Leaf washings

For the determination of ^{32}P activity in the leaf washings, one ml of the washing was taken in a scintillation vial and made upto 20 ml using distilled water. The radioactivity in the washing was determined by Cerenkov counting technique in a microprocessor-controlled liquid scintillation system (Pharmacia LKB Wallac OY, Finland) following the programme for the liquid scintillation counting of tritium. The radioactivity in the washings was recorded as cpm after making background correction. The difference in radioactivity between the applied dose and the radioactivity recorded in the leaf washings (unabsorbed portion) was taken as the fraction absorbed by the leaf.

b. Plant material

For the determination of ^{32}P activity in the plant material, Cerenkov counting method developed by Wahid _et al_. (1985) was followed. The method involved wet digestion of 1 g of oven-dried and finely cut leaves with 2:1 nitric-perchloric acid mixture followed by transferring the digest into a scintillation counting vial with distilled water upto a final volume of 20 ml. The vials with the contents were left undisturbed for four hours for the silica in the digest to settle down. Later the radioactivity in the vial containing the acid digest was determined in a microprocessor-controlled liquid scintillation system (Pharmacia LKB Wallac OY, Finland) following the programme for the liquid scintillation counting of tritium. The radioactivity was recorded as cpm after making background correction.

Part I Development of a method to study the absorption of foliar applied ^{14}C-urea and ^{32}P

a. Experiment to standardise the leaf age and leaf surface to study the foliar absorption

Before taking up detailed studies on foliar absorption, an experiment was conducted to standardise the leaf age and leaf surface to study the foliar absorption in cashew seedlings.

Twelve seedlings of uniform growth were selected for the study. There were four treatments involving combination of two leaf positions and two leaf surfaces (second leaf-upper surface, second leaf-lower surface, seventh leaf-upper surface and seventh leaf-lower surface) with three replications. On the selected leaves, 100 µl of ^{32}P solution with known activity (19.4 µCi ml^{-1}) was applied as 10 minute droplets on the lamina with the help of a microsyringe as shown in Plate 1. The application was done at about 10 a.m. The seedlings were watered regularly and left in the glass house for a period of five days to allow foliar absorption. After five days, the treated leaves from every plant were separated and washed with a jet of running solution (10 ml of 0.5 per cent teepol). After washing, the leaves were rinsed with distilled water. To quantify the ^{32}P absorbed by the plant, the treated leaves (after washing) and the other plant parts were subjected to radioassay.

From the results obtained from this experiment the leaf surface and leaf position was decided for conducting further studies.

Plate 1. Method followed for the foliar application of labelled materials (^{14}C-urea and ^{32}P) for the study.

b. Method to study the foliar absorption of ^{14}C-urea

The study was aimed to develop a method to quantify the absorption of foliar applied ^{14}C-urea by cashew leaves. Based on the results of the Part I.a., the lower surface of the second leaf from the top was chosen for the study. On this surface, 50 µl of ^{14}C-urea solution with known activity (1.5 µCi ml^{-1}) was spotted around 10 a.m. with the help of a microsyringe so that the applied solution adhered to the leaf surface as minute droplets. Sufficient care was taken to ensure that the activity applied on the leaf was not spilled over to any other neighbouring leaves. The seedlings were watered regularly and kept in the glass house for a period of five days.

At the end of the fifth day, every leaf was subjected to a sequential washing programme involving eight washings (each for 30 s), at every stage with 50 ml each of 2 per cent teepol solution. The washings at each stage were collected separately, and subjected to radioassay to ascertain at which stage of washing, the adsorbed radioactivity was minimum or low. The experiment was repeated thrice and the mean worked out.

c) Method to study the foliar absorption of ^{32}P

The study was aimed to develop a method to quantify the absorption of foliar applied ^{32}P by cashew leaves. The treatments, materials and methods were the same as described in Part I.b. excepting the quantity of ^{32}P applied and the method of radioassay followed. The quantity of ^{32}P applied on each leaf was 50 μl of ^{32}P solution with activity of 12.3 μci ml^{-1}. The radioassay of the washings collected at each stage were recorded.

From the results obtained a sequential washing programme involving four washing using 50 ml of 2 per cent teepol was considered as reasonable for quantifying the adsorbed ^{14}C-urea and ^{32}P on cashew leaves and the composite washing solution (200 ml) was used for radioassay. Based on these experiments subsequent studies using ^{14}C-urea and ^{32}P were conducted.

Part II. **Factors affecting foliar absorption**

a. Foliar absorption of ^{14}C-urea by cashew seedlings in relation to leaf position and leaf surface

A glass house cum laboratory experiment was conducted during July 1993 to study the absorption of foliar applied ^{14}C-urea by cashew seedlings in relation to leaf surface and leaf position. Twelve seedlings of more or less uniform growth were selected for the study. In order to assess the variation in the absorption of foliar applied ^{14}C-urea in relation to leaf position and leaf surface, two leaf positions (second leaf from top and seventh leaf from top) and two leaf surfaces (upper surface, lower surface) were considered as treatments(Fig.2). Thus there were four treatments involving combinations of two leaf positions and two leaf surfaces (second leaf upper surface, second leaf lower surface, seventh leaf upper surface and seventh leaf lower surface). The experiment was treated as in CRD with four treatments and three replications.

On every selected leaf, on the leaf surface specified, 50 µl of ^{14}C-urea solution with known activity (1.5 µCi ml^{-1}) was spotted around 11 a.m. and the seedlings were kept in the glass house for a period of five days. At the end of the fifth day, the treated leaves from every plant were separated and washed as per the washing procedure developed and the washings were taken for radioassay.

b. Foliar absorption of ^{32}P by cashew seedlings in relation to leaf position and leaf surface

A glass house cum laboratory experiment was conducted during August 1993 to study the absorption of foliar applied ^{32}P by cashew seedlings in relation to leaf surface and leaf position. The treatments, materials and methods were the same as described in Part II.a excepting the quantity of ^{32}P applied. The quantity of ^{32}P applied on each leaf was 50 µl of ^{32}P solution with activity of 100 µCi ml^{-1}. All the leaves including treated leaf (after washing) were

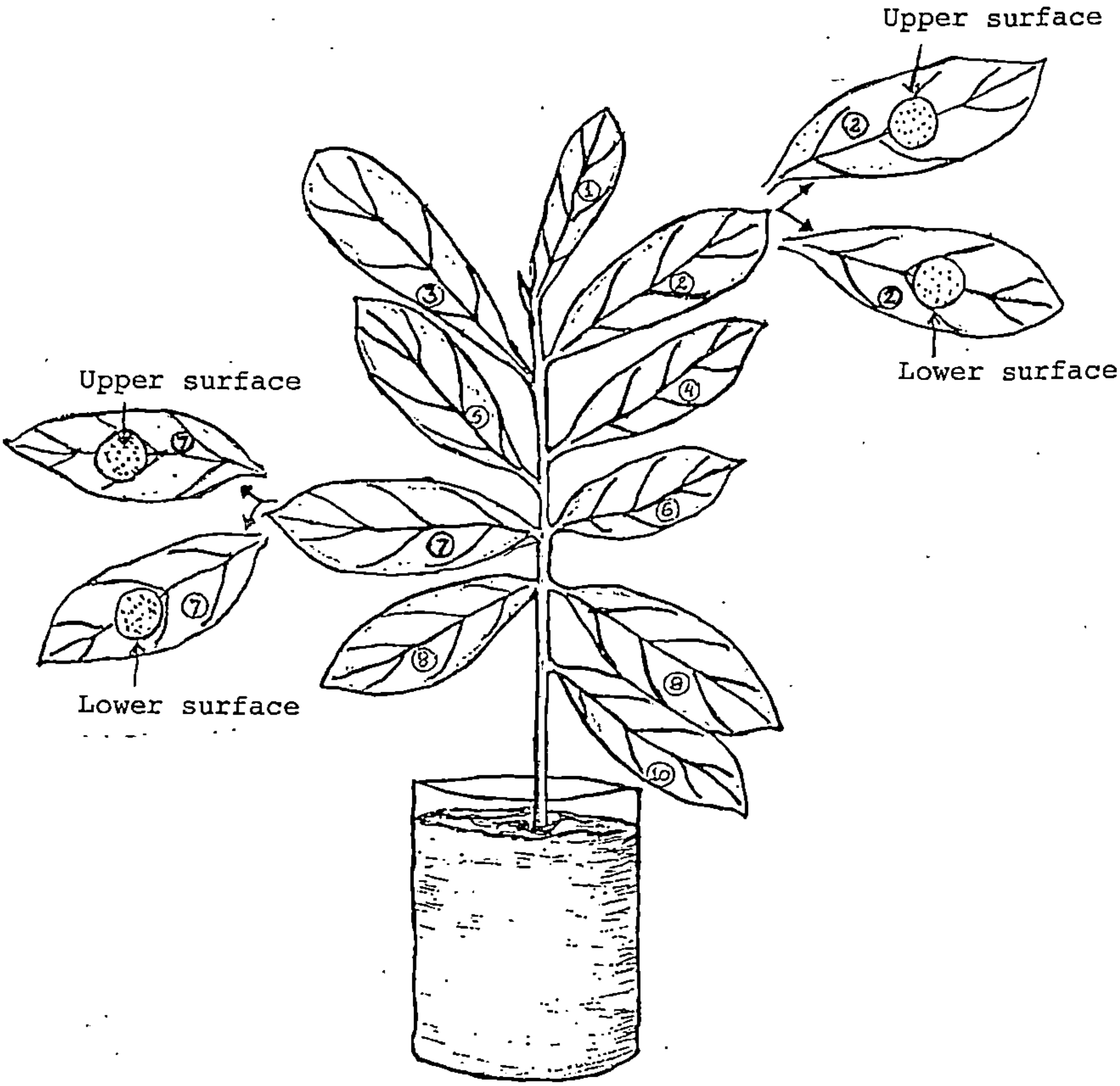


Fig.2. Leaf positions and leaf surfaces chosen to study the absorption of ^{14}C-urea and ^{32}P by cashew seedlings

numbered from the top, and the stems and roots were collected individually and radioassayed.

c. Foliar absorption of ^{14}C-urea by cashew seedlings in relation to leaf age

A glass house cum laboratory experiment was conducted during August 1993 to study the absorption of foliar applied ^{14}C-urea in relation to the age of leaf in cashew seedlings. The treatments involved 11 ages of leaf measured in terms of the position of leaf from the terminal end to the bottom of the seedlings (Fig.3).

Three seedlings each containing 11 leaves in total were selected for this study and the leaves were numbered and marked with the help of tags. The experiment was considered as in CRD with 11 treatments (leaf ages) and three replications. The lower sides of every leaf was spotted with 50 µl of ^{14}C-urea solution with known activity (1.5 µCi ml^{-1}) around 7 a.m. and the seedlings were left in the glass house for a period of five days. At the end of the fifth day, the leaves were removed separately and washed as per the sequential washing procedure developed. The radioactivity in the washings was recorded.

d. Foliar absorption of ^{32}P by cashew seedlings in relation to leaf age

A glass house cum laboratory experiment was conducted during August 1993 to study the absorption of foliar applied

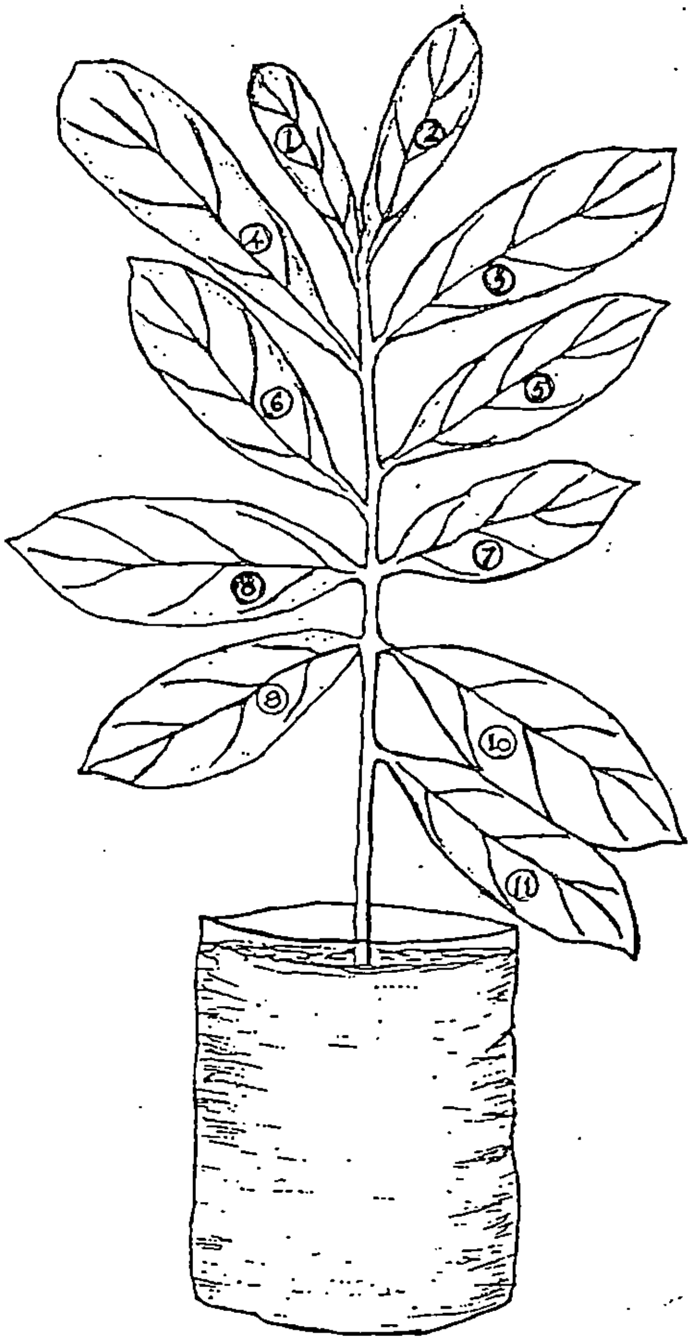


Fig.3. Leaf age in terms of leaf position, considered to study the foliar absorption of ^{14}C-urea and ^{32}P by cashew seedlings.

^{32}P in relation to the age of leaf in cashew seedlings. The treatments, materials and methods were the same as described in Part II.c excepting the quantity of ^{32}P applied. The quantity of ^{32}P applied on each leaf was 50 µl of ^{32}P solution with activity of 14.9 µCi ml^{-1}. The washings collected from the treated leaves were radioassayed.

e. Foliar absorption of ^{14}C-urea in relation to duration of absorption and leaf surface

A glass house cum laboratory experiment was conducted during August 1993 to study the absorption of foliar applied ^{14}C-urea in relation to duration of absorption and leaf surface in cashew seedlings. The treatments involved combinations of 10 durations of absorption (4, 8, 12, 24, 48, 72, 96, 120, 144 and 168 hours) and two leaf surfaces (upper and lower). The experimental design was CRD with 20 treatments and three replications. The second leaf from the top was chosen for application of ^{14}C-urea. As per treatment, the selected surface of the leaves were spotted with 100 µl of ^{14}C-urea solution with known activity (1.5 µCi ml^{-1}) around 7 a.m. and the seedlings were left in the glass house for the different durations fixed.

After the specified durations, the treated leaves were separated and washed as per the sequential washing procedure standardised. The washings collected were radioassayed.

f. Foliar absorption of ^{32}P in relation to duration of absorption and leaf surface

A glass house cum laboratory experiment was conducted during August 1993 to study the absorption of foliar applied ^{32}P in relation to duration of absorption and leaf surface in cashew seedlings. The treatments, materials and methods were the same as that described in Part II.e excepting the quantity of ^{32}P applied. The quantity of ^{32}P applied on each leaf was 50 µl of ^{32}P solution with activity of 67.7 µCi ml^{-1}. The washings collected from the treated leaves were radioassayed.

g. Diurnal variation in the foliar absorption of ^{14}C-urea

A glass house cum laboratory experiment was conducted during February 1994 to study the diurnal variation in absorption of foliar applied ^{14}C-urea by cashew seedlings. Seedlings of more or less uniform growth, size and leaf number were selected for the study. The variation in foliar absorption in relation to time of the day from 07 00 hours to 17 00 hours (at one hour interval) was studied on nineteenth February, 1994. The experiment was treated as in CRD with 11 treatments (time of the day) and three replications.

The lower surface of the second leaf from the top was spotted with 100 µl of ^{14}C-urea solution with known activity

(1.5 µCi ml^{-1}). The first application started at 07.00 h in the morning and the subsequent applications were done at one hour interval upto 17 00 hours. After one hour of every application, the treated leaf was separated and washed as per the sequential washing procedure developed. The radioactivity in the washings was recorded.

h. Diurnal variation in the foliar absorption of ^{32}P

A glass house cum laboratory experiment was conducted during February, 1994 to study the diurnal variation in the absorption of foliar applied ^{32}P by three months old cashew seedlings. The treatments, materials and methods were the same as those described in Part II.g excepting the quantity of ^{32}P applied. The quantity of ^{32}P applied on each leaf was 100 µl of ^{32}P solution with activity of 24 µCi ml^{-1}. The washings collected from the treated leaves were used for radioassay.

i. Effect of teepol on foliar absorption of ^{14}C-urea.

A glass house cum laboratory experiment was conducted during March 1994 to study the effect of different concentrations of teepol on the foliar absorption of ^{14}C-urea by cashew seedlings. Three month old cashew seedlings of more or less uniform growth were selected. The treatments involved three concentrations of teepol viz. 0, 0.05 and 0.15 per cent. The experimental design was CRD with three treatments (concentration of teepol) and three replications.

The lower surface of the second leaf from top was smeared with 50 µl of teepol solution around 7 a.m. After one minute, the teepol smeared area was spotted with 100 µl of ^{14}C-urea solution with known activity (1.5 µCi ml^{-1}) and the seedlings were left in the glass house for eight hours. After eight hours, the treated leaves were separated and washed as per the sequential washing procedure developed. The radioactivity in the washings was recorded.

j. Effect of teepol on foliar absorption of ^{32}P

A glass house cum laboratory experiment was conducted during March 1994 to study the effect of different concentrations of teepol on the foliar absorption of ^{32}P by cashew seedlings. The treatments, materials and methods were the same as those described in Part II.i excepting the quantity of ^{32}P applied. The quantity of ^{32}P applied on each leaf was 50 µl of ^{32}P solution with activity of 12.6 µCi ml^{-1}. The washings collected from the treated leaves were radioassayed.

k. Monthly variation on foliar absorption of ^{14}C-urea in relation to leaf age and leaf surface

The objective of this experiment was to study the monthly variation on foliar absorption of ^{14}C-urea in relation to leaf age and leaf surface by cashew tree (history of the experimental trees is given on page26). The treatments involved combinations of three leaf ages (latest flush - terminal leaves, latest flush - central leaves and latest flush - basal leaves as shown in Fig. 4) and two leaf surfaces (upper surface and lower surface). The experiment was done during two months (February and March).

The experiment was treated as in CRD with three replications. The selected leaves on the trees were marked with the help of tags. On every selected leaf 100 μl of ^{14}C-urea solution with known activity (1.5 μ Ci ml^{-1}) was applied around 12 noon on second February 1994 and fifth March 1994. The trees were left as such for a period of five days. There was no rain during this period. After five days, the treated leaves from every plant were separated and washed as per the procedure standardised and the washings collected were radioassayed. The radioactivity in the neighbouring leaves of the treated leaves were radioassayed using a biological sample oxidizer to confirm whether the applied ^{14}C-urea was absorbed and translocated.

1. Monthly variation on foliar absorption of ^{32}P in relation to leaf age and leaf surface

The objective of this experiment was to study the monthly variation on foliar absorption of ^{32}P in relation to

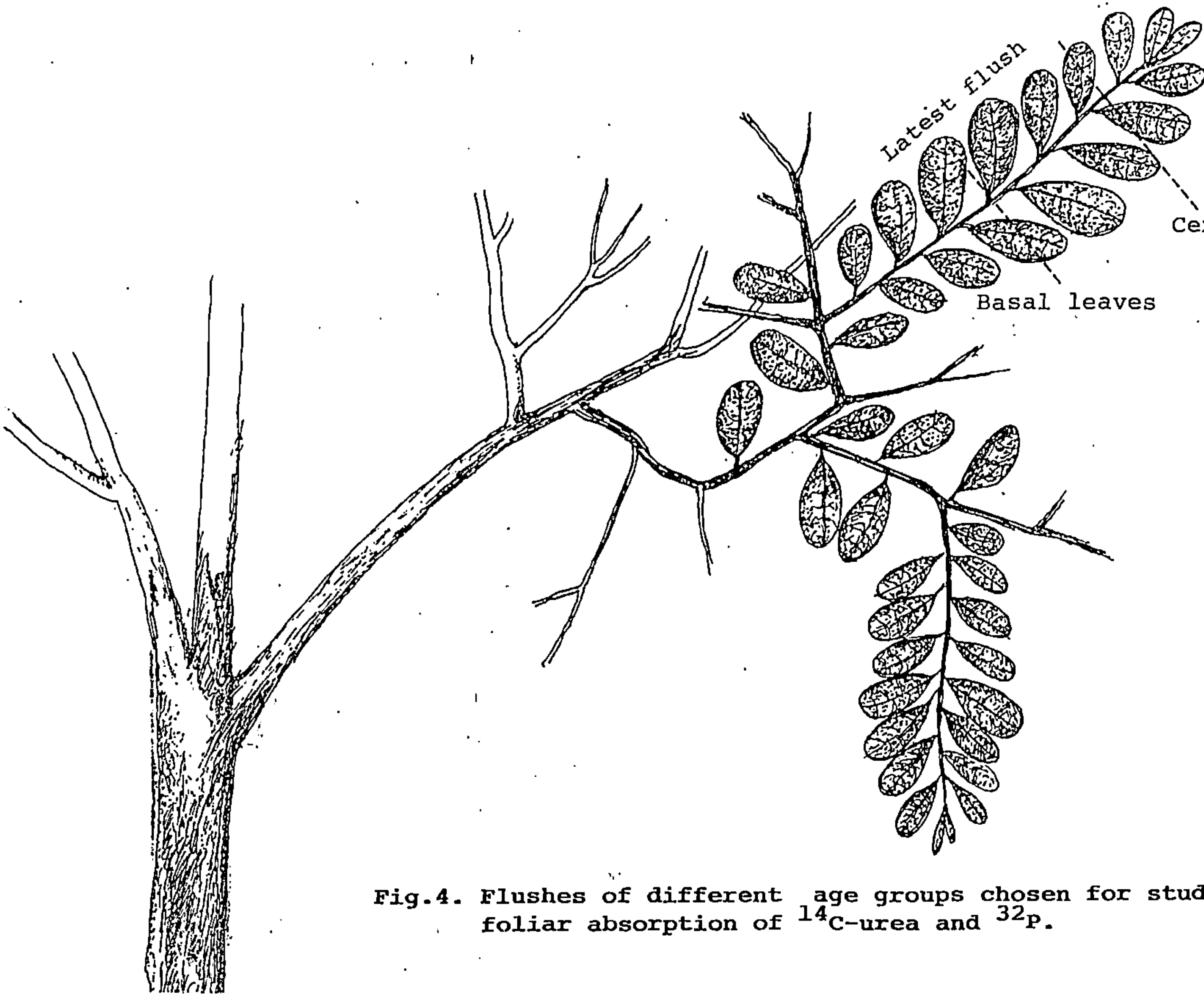


Fig.4. Flushes of different age groups chosen for studying the foliar absorption of ^{14}C-urea and ^{32}P.

leaf age and leaf surface of cashew trees. The treatments, materials and methods were the same as those described in Part II.k excepting the months of application and the quantity of ^{32}P applied. The experiment was done during December, February and March and the quantity of ^{32}P applied on each leaf was 50 µl of ^{32}P solution with activity of 5.4 µCi ml^{-1} during December, 48 µCi ml^{-1} during February and March. The ^{32}P solution was applied around 1 p.m. on seventeenth December 1993, second February 1994 and fifth March 1994. The washings collected from the treated leaves were radioassayed.

The neighbouring leaves near to the treated leaf was also taken for radioassay to find out whether the applied ^{32}P was absorbed and translocated from the treated leaf.

Part III. Root absorption of ^{14}C-urea and ^{32}P by cashew seedlings

a. Root absorption of ^{14}C-urea

A green house cum laboratory experiment was conducted during November 1993 to study the absorption of ^{14}C-urea through roots of three month old cashew seedlings. Seedlings with more or less uniform growth, size, leaf number and root system development were selected for the study. All the selected seedlings in the experiment contained 11 leaves at the time of the experiment. With the help of a jet of water, the soil was removed from the roots so that root system damage was the least.

The absorption pattern was studied in relation to five durations (4, 8, 12, 24 and 48 hours). The experiment was treated as in CRD with five treatments (durations of absorption) and four replications. The cleaned root portion of the selected seedlings were kept immersed in a conical flask (Fig.5) containing 250 ml of ^{14}C-urea (100 μl of solution with radioactivity 8.6 μCi ml^{-1}) at 07 00 h. The plants were held upright by cotton plugging at the flask mouth, around the stem portion of the plant. Initial activity of the feeding solution (in the flask) before root dipping was determined from every conical flask without adding HCl.

The level of the solution in the flask before root dipping was marked with a pen. After specified time intervals of root feeding (4, 8, 12, 24 and 48 hours), the seedlings were removed from the flask and made up the volume in the flask to the initial marked level. One ml of the solution was then taken from each flask and the radioactivity was determined (without adding HCl).

The difference in radioactivity in the feeding solution before and after root dipping was taken as the amount of ^{32}P absorbed by the plant.

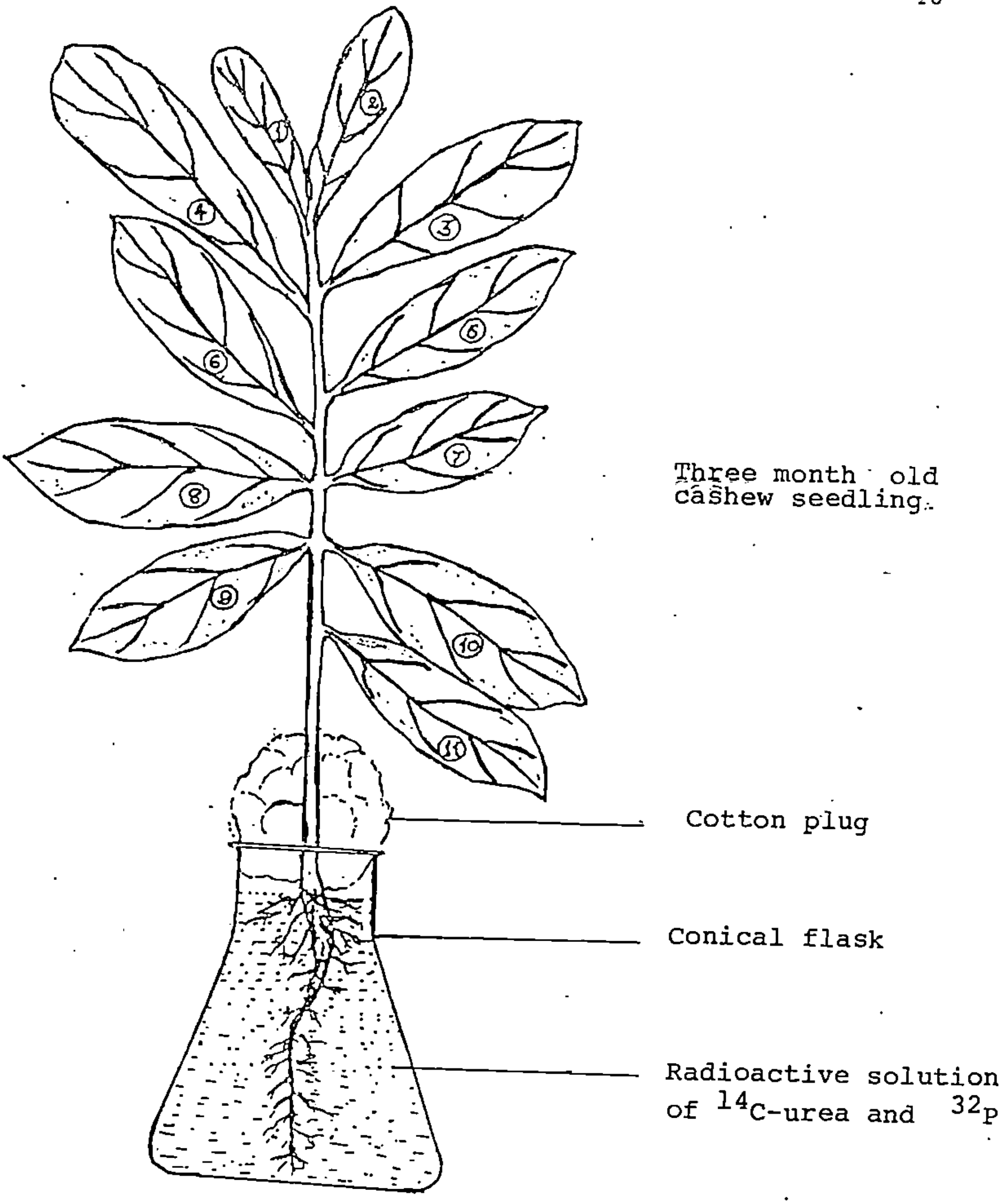


Fig.5. Diagram showing the method for studying the root absorption of ^{14}C-urea and ^{32}P by cashew seedlings

b. Root absorption of ^{32}P

A green house cum laboratory experiment was conducted during November 1993 to study the absorption of ^{32}P through roots of three month old cashew seedlings The treatments, materials and methods were the same as that described in Part III.a excepting the quantity of ^{32}P applied into the flask. Every conical flask contained 250 ml of ^{32}P solution (100 μl of solution with radioactivity of 22.7 $\mu Ci\ ml^{-1}$). The radioactivity of the sample in the flask before and after root feeding was measured. The difference in radioactivity in the feeding solution before and after root dipping was taken as the amount absorbed by the plants.

Part IV. **Studies on leaf anatomy in relation to foliar absorption**

The objective was to study the leaf anatomy in relation to leaf age and leaf surface and to explain the influence of anatomical characters on foliar absorption.

a. Cuticle thickness

Cuticle thickness was measured in relation to the age of leaves. Latest flush and the previous season flush were selected from a six year old cashew during December 1993 and classified into three age groups. The three age groups selected for the study were terminal leaves of the latest flush (about one weak old), basal leaves of the latest flush (about 6 weeks old) and leaves of the previous season flush (about 18 week old).

Leaf sections were prepared by the cryostat method (Norris, 1973). The tissue was embedded in a supporting medium of water and the frozen specimens were sectioned at 12 µm with a freeze microtome (minotome). The sections were stained by Sudan - IV (Locquin and Langerson, 1978) which was prepared by dissolving 0.5 g of the dye in 100 ml of 70 per cent alcohol. The sections were kept in the stain for 20 minute and mounted on a slide with glycerol (Johansen, 1940). The measurements on cuticle thickness (upper and lower surfaces) were made with a calibrated eye piece micrometer in the region of the intense red stained cuticle overlying the epidermal cell wall. Thirty measurements were taken from sections from different spots of both upper and lower surfaces and the means worked out. Photomicrographs were also taken with a 'Leitz Dialux-20' microscope fitted with vario orthomat camera.

b. Stomatal index

The number of stomata per unit leaf area was counted in relation to age of leaf. Leaves of three age groups chosen for measuring the cuticle thickness (Part IV.a) were used for recording the number of stomata per unit leaf area.

Leaf peelings were taken from the upper and lower surfaces using a blade. The peelings were dipped in 100 per cent acetone for 24 hours and were made chlorophyll free. The peelings were then washed in water and stained with safranine for one minute (Johansen, 1940). The stained samples were washed in water and mounted on a slide with glycerol. Stomatal counts per unit area were taken from 20 spots from upper and lower surfaces of leaves with the help of 'Leitz Dialux 20' microscope and the means worked out. The photomicrographs were also taken with a 'Leitz Dialux 20' microscope fitted with vario orthomat camera.

Part V. **Canopy analysis in cashew**

The objective of the study was to quantify and apportion the leaf area of cashew trees in relation to age of flush. Three trees of uniform growth were selected for the study. The canopy analysis was done in November 1993 during which the trees were at flushing and flowering phase. Based on age the leaves in the canopy were broadly classified into five groups namely terminal leaves of latest flush (one week old), central leaves of latest flush (three weeks old), basal leaves of latest flush (six weeks old), leaves of the previous season flush (18 weeks old) and leaves of the one year old branches. There were five treatments (leaf ages) and three replications. Single tree was considered as a replication.

From every tree, three leaves from each age group were randomly selected and leaf area was measured with the help of a graph paper and the mean leaf area was worked out. The number of leaves present in the tree under each age group was also recorded by counting The total leaf area under each age group was calculated as a product of number of leaves in each age group and mean leaf area. The leaf area was expressed as m^2. The percentage of leaf area, under each age group, to the total leaf area of the plant was also worked out.

Statistical analysis

The data relating to single factor experiments were statistically analysed applying the analysis of variance for completely randomised design. In the case of multiple factor experiments the data were analysed applying the analysis of variance for factorial experiments in completely randomised design. All the data relating to radioactivity counts were subjected to suitable transformation ($\log/\sqrt{x+1}$) prior to statistical analysis and the test of significance was done using F and t-tests (Panse and Sukhatme, 1978). The abstract of analysis of variance is given in Appendix 1 to 17.

Results

RESULTS

The results of the various experiments conducted during the course of the investigation are presented below.

Part I. Development of a method to study the foliar absorption of ^{14}C-urea and ^{32}P

a. Experiment to standardise the leaf age and leaf surface to study the foliar absorption.

There was considerable difference in foliar absorption of ^{32}P between the second leaf and seventh leaf from the top (Table 1). The foliar absorption was highest in the younger leaves. Between the two surfaces, foliar absorption was the highest through the lower surface compared to the upper one. Based on the results of this experiment, it was decided to choose the lower surface of the second leaf for further detailed studies on foliar absorption.

b. Method to study the foliar absorption of ^{14}C-urea

The data on the radioactivity in the leaf washings are given in Table 2. The radioactivity was the highest in the first washing and it declined drastically from the second washing onwards (Fig. 6). The radioactivity in the second, third and fourth washings did not differ much. Though the radioactivity counts were detected upto the eighth washing, the values were extremely small.

Table. 1. Foliar absorption of ^{32}P in relation to leaf position and leaf surface

Treatments	Amount absorbed (log cpm)
Leaf position	
Second leaf from top	6.252 (1786183)
Seventh leaf from top	6.039 (1094384)
SEm$\pm$	0.035
CD (0.05)	0.114
Leaf surface	
Upper	6.055 (1134406)
Lower	6.242 (1746161)
SEm$\pm$	0.035
CD (0.05)	0.114
Position and Surface	
Second leaf upper	6.139 (1379263)
Second leaf lower	6.341 (2193102)
Seventh leaf upper	5.949 (889548)
Seventh leaf lower	6.114 (1299220)
SEm$\pm$	0.049
CD (0.05)	NS

Figures in the parentheses denote count in cpm

Table 2. Radioactivity (cpm) in the washings from cashew leaves applied with ^{14}C-urea and ^{32}P in relation to the number of washings

No. of Washings	^{14}C urea: Amount of radioactivity in the washing (cpm($\sqrt{x}$+1))	^{32}P: Amount of radioactivity in the washing (log cpm)
First washing	80.453 (6167)[a]	5.074 (119812)[a]
Second ,,	28.813 (850)[b]	4.44 (27723)[b]
Third ,,	25.98 (700)[bc]	4.167 (14823)[c]
Fourth ,,	21.983 (733)[bc]	4.036 (11114)[c]
Fifth ,,	12.993 (333)[bc]	3.77 (6070)[d]
Sixth ,,	3.820 (20)[c]	3.749 (5707)[d]
Seventh ,,	4.017 (33)[c]	3.554 (3963)[de]
Eighth ,,	6.45 (100)[c]	3.492 (3490)[e]
SEm$\pm$	6.55	0.08
CD(0.05)	19.63	0.24

Figures in the parentheses denote count in cpm

Data followed by the same alphabet are not significantly different.

Fig.6 Radioactivity(cpm) in the sequential washings from cashew leaves applied with ^{14}C - urea

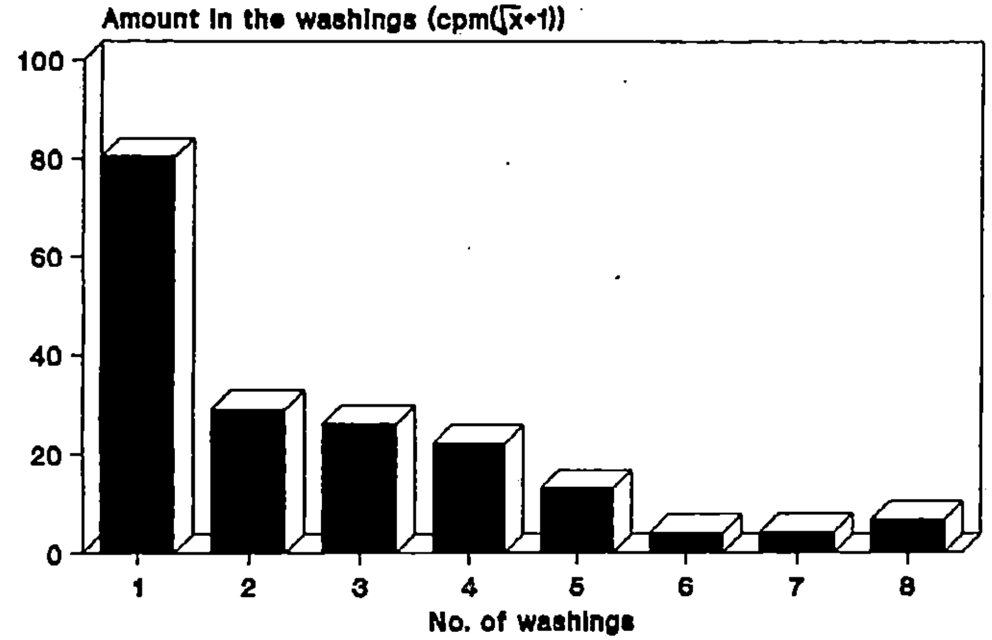
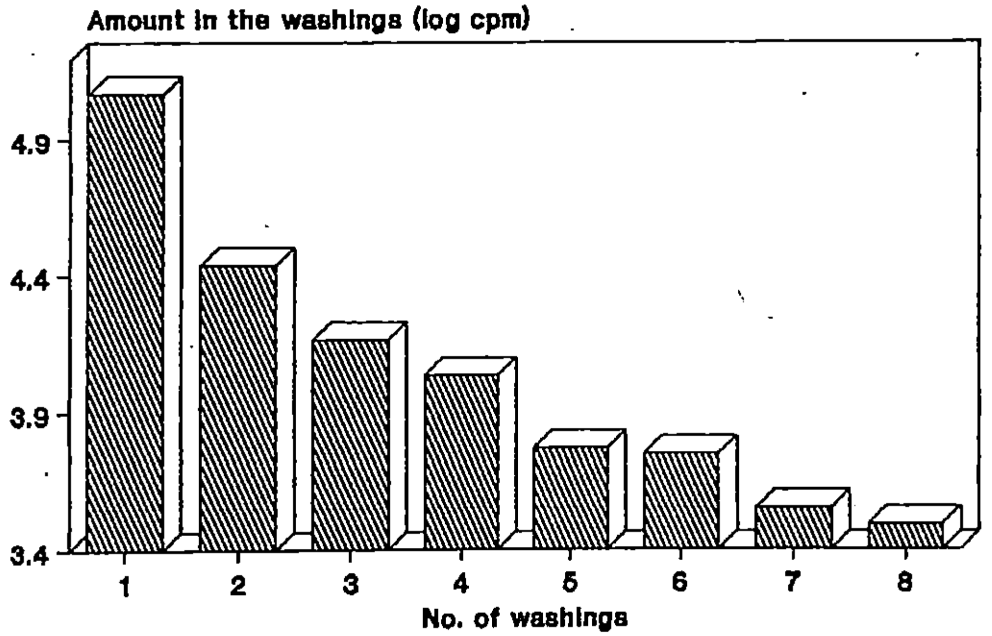


Fig.7 Radioactivity(cpm) in the sequential washings from cashew leaves applied with ^{32}P



c. Method to study the foliar absorption of ^{32}P

The pattern of release of the adsorbed ^{32}P (Table 2) from the leaf surface was similar to that observed with ^{14}C-urea. The radioactivity in the first washing was the highest and the amount declined thereafter (Fig.7). The radioactivity counts from the fourth washing onwards were very low and were detected in all the samples collected upto the eighth washing.

Part II. Factors affecting foliar absorption

a. Foliar absorption of ^{14}C-urea by cashew seedlings in relation to leaf position and leaf surface

The foliar absorption of ^{14}C-urea did not differ between the leaves, positioned second and seventh from the top of the seedlings (Table 3). But there was considerable difference in the foliar absorption of ^{14}C-urea between the upper and lower surfaces of the leaf. The absorption was higher through the lower surface compared to the upper one. The percentage absorption of the applied urea was 61 per cent through the upper surface, while it was about 84 per cent through the lower surface. The interaction between the leaf surface and leaf position on foliar absorption of urea was absent.

Table 3. Foliar absorption of ^{14}C-urea by cashew seedlings in relation to leaf position and leaf surface

Treatments	Amount absorbed (log cpm)	Per cent absorption
Leaf position		
Second leaf from top	4.364 (23511)	74.23
Seventh leaf from top	4.344 (22575)	71.288
SEm±	0.021	1.932
CD (0.05)	NS	NS
Leaf surface		
Upper	4.281 (19347)	61.09
Lower	4.426 (26739)	84.42
SEm±	0.021	1.932
CD (0.05)	0.065	5.913
Position and surface		
Second leaf upper	4.291 (19679)	62.13
Second leaf lower	4.437 (27343)	86.33
Seventh leaf upper	4.271 (19015)	60.04
Seventh leaf lower	4.416 (26135)	82.51
SEm±	0.032	2.732
CD (0.05)	NS	NS

Figures in the parentheses denote count in cpm

b. Foliar absorption of ^{32}P by cashew seedlings in relation to leaf position and leaf surface

Foliar absorption of ^{32}P differed due to leaf position and leaf surface (Table 4). The younger leaf at the top absorbed more ^{32}P (amount and percent) compared to older leaf at the bottom. Similarly, the absorption was more through the lower surface. The interaction between the leaf position and leaf surface was significant and the absorption was high when application was done on lower surface of the second leaf from top.

The radioactivity in the treated leaf (after washing) varied due to leaf position, application surface of the leaf and their interaction. The lower surface of second leaf applied with ^{32}P absorbed more amount compared to the leaves on which ^{32}P was applied on the upper surface.

Translocation from the treated leaf differed due to leaf surface and it was high when nutrient was applied on the lower surface. About 98.7 per cent of the absorbed ^{32}P was retained in the treated leaf and only 1.3 per cent was translocated when ^{32}P application was done on the upper surface (Fig.8). But when ^{32}P was applied through the lower surface, 96 per cent was retained in the treated leaf and 4 per cent was translocated (Fig. 9).

Table 4. Foliar absorption of ^{32}P by cashew seedlings in relation to leaf position and leaf surface

Treatments	Amount absorbed (log cpm)	Per cent absorption	Content in the treated leaf after washing (log cpm)	Amount translocated from the treated leaf (log cpm)
Leaf position				
Second leaf from top	5.14 (140679)	35.19	5.138 (137497)	3.432 (3832)
Seventh leaf from top	5.03 (116266)	29.11	5.051 (112434)	3.306 (3183)
SEm±	0.024	0.977	0.028	0.098
CD (0.05)	0.255	3.19	0.091	NS
Leaf surface				
Upper	4.963 (95738)	23.95	4.976 (94519)	3.009 (1219)
Lower	5.207 (161207)	40.36	5.191 (155412)	3.729 (5796)
SEm±	0.024	0.977	0.028	0.098
CD (0.05)	0.255	3.19	0.091	0.319
Position and surface				
Second leaf upper	5.071 (119050)[b]	29.78[b]	5.073 (118217)[a]	3.124 (1604)
Second leaf lower	5.209 (160106)[a]	40.61[a]	5.195 (156776)[a]	3.74 (6059)
Seventh leaf upper	4.856 (72425)[c]	18.12[c]	4.85 (70821)[b]	2.894 (834)
Seventh leaf lower	5.204 (162308)[a]	40.1[a]	5.188 (154047)[a]	3.719 (5532)
SEm±	0.034	1.38	0.039	0.1388
CD (0.05)	0.111	4.503	0.1288	NS

Figures in the parentheses denote count in cpm.

Data followed by the same alphabet are not signifcantly different

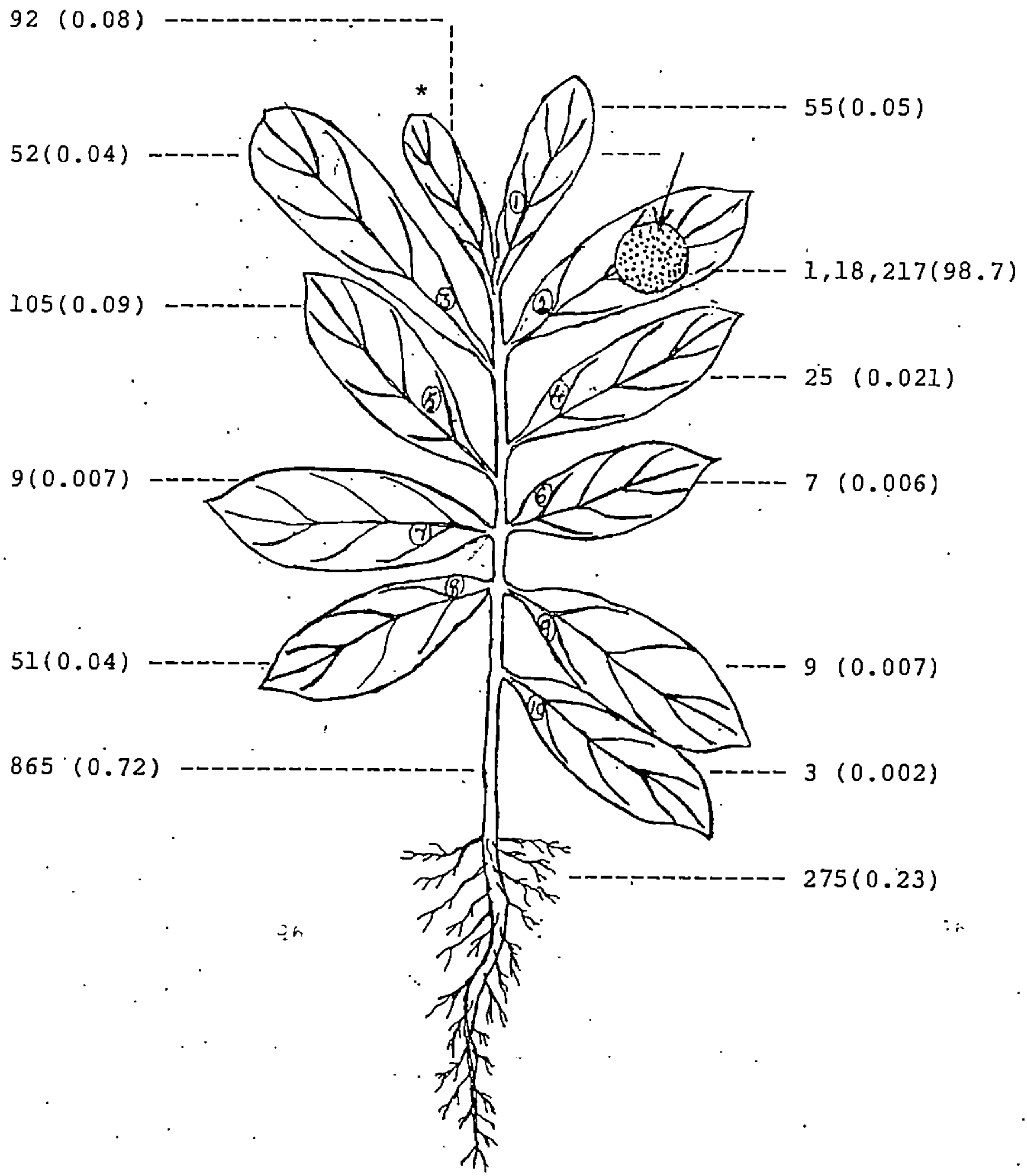


Fig.8. Absorption and distribution of ^{32}P (cpm) by cashew seedlings. ^{32}P is applied on upper surface of second leaf. (Figures in bracket indicate percentage absorption to total).

* New leaf emerged during the experimental period.

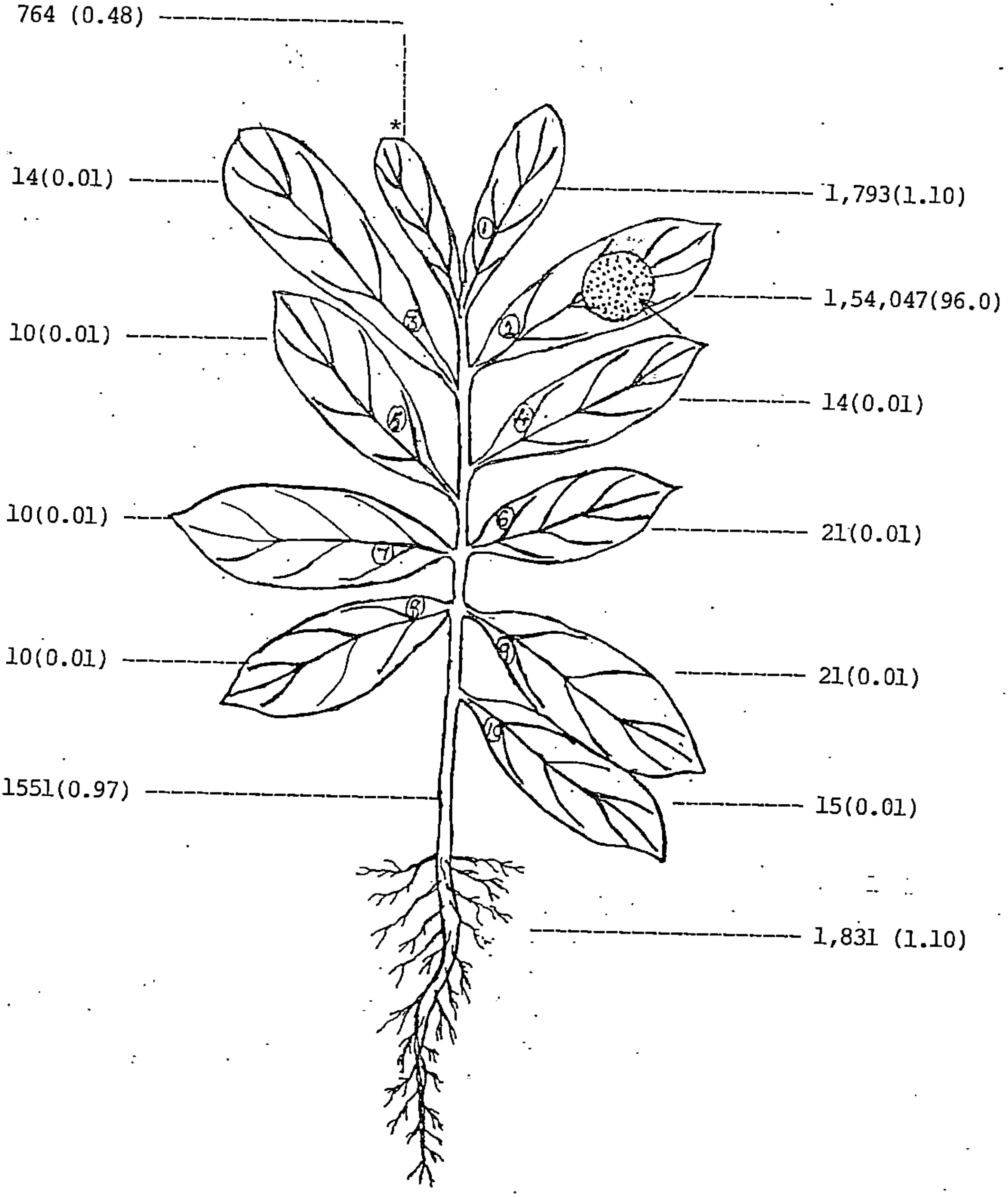


Fig.9. Absorption and distribution of ^{32}P (cpm) by cashew seedlings. ^{32}P is applied on lower surface of second leaf. (Figures in bracket indicate percentage absorption to total)

* New leaf emerged during the experimental period.

c. Foliar absorption of ^{14}C-urea in relation to leaf age

Foliar absorption of ^{14}C-urea by cashew leaves varied with leaf age (Table 5). The absorption was the highest in the young leaves at the terminal end and it declined with the age of the leaf. Both the amount as well as the per cent of absorption were high with the first four leaves at the top and the absorption was low with the lower leaves. While the youngest leaf at the terminal end absorbed as much as 89 per cent of the applied ^{14}C-urea, the oldest leaf at the bottom could absorb only about 60 per cent (Fig. 10).

d. Foliar absorption of ^{32}P in relation to leaf age

The foliar absorption of ^{32}P varied with leaf age (Table 5). As in the case of foliar absorption of ^{14}C-urea, the foliar absorption of ^{32}P was also the highest with the youngest leaves at the terminal end and absorption was lowest with the oldest leaves at the bottom. The younger leaves at the terminal end absorbed 55-65 per cent of the ^{32}P while the older leaves at the bottom absorbed only 42-46 per cent (Fig.11).

An attempt was also made to compare the difference in the foliar absorption of ^{14}C-urea and ^{32}P by cashew seedlings (Table 6). The cashew seedlings absorbed foliar applied ^{14}C-urea and ^{32}P at different rates. The foliar

Table 5. Foliar absorption of ^{14}C-urea and ^{32}P in relation to leaf age

Leaf number from top	^{14}C-urea		^{32}P	
	Amount absorbed (log cpm)	Per cent absorption	Amount absorbed (log cpm)	Per cent absorption
First leaf	4.328 (21295)^{a}	88.91^{a}	5.245 (175790)^{a}	65.21^{a}
Second ,,	4.32 (20883)^{a}	87.19^{ab}	5.169 (150754)^{ab}	55.93^{ab}
Third ,,	4.276 (18877)^{ab}	78.81^{ab}	5.051 (116512)^{b}	43.22^{b}
Fourth ,,	4.279 (19010)^{ab}	79.36^{ab}	4.993 (98406)^{b}	36.5^{b}
Fifth ,,	4.265 (18463)^{ab}	77.09^{b}	5.008 (104944)^{b}	38.93^{b}
Sixth ,,	4.256 (18014)^{ab}	75.21^{b}	4.967 (96009)^{b}	35.61^{b}
Seventh ,,	4.232 (17182)^{b}	71.74^{bc}	5.188 (154640)^{ab}	57.36^{ab}
Eighth ,,	4.205 (16130)^{b}	67.34^{bc}	5.176 (150029)^{ab}	55.65^{ab}
Ninth ,,	4.167 (14880)^{b}	62.12^{c}	5.091 (124965)^{b}	46.36^{b}
Tenth ,,	4.214 (16370)^{b}	68.21^{bc}	5.141 (139759)^{ab}	46.07^{b}
Eleventh ,,	4.149 (143.50)^{b}	59.90^{c}	5.060 (115070)^{b}	42.69^{b}
SEm$\pm$	0.03	4.27	0.05	5.141
CD (0.05)	0.088	10.754	0.147	11.879

Table 6. Variation in absorption (%) of ^{14}C-urea and ^{32}P by cashew seedlings

Treatement	Per cent absorption
^{14}C-urea	74.17
^{32}P	47.59
t-value	10.1 (significant at 1 % level)

Figures in the parentheses denote count in cpm.
Data followed by the same alphabet are not significantly different.

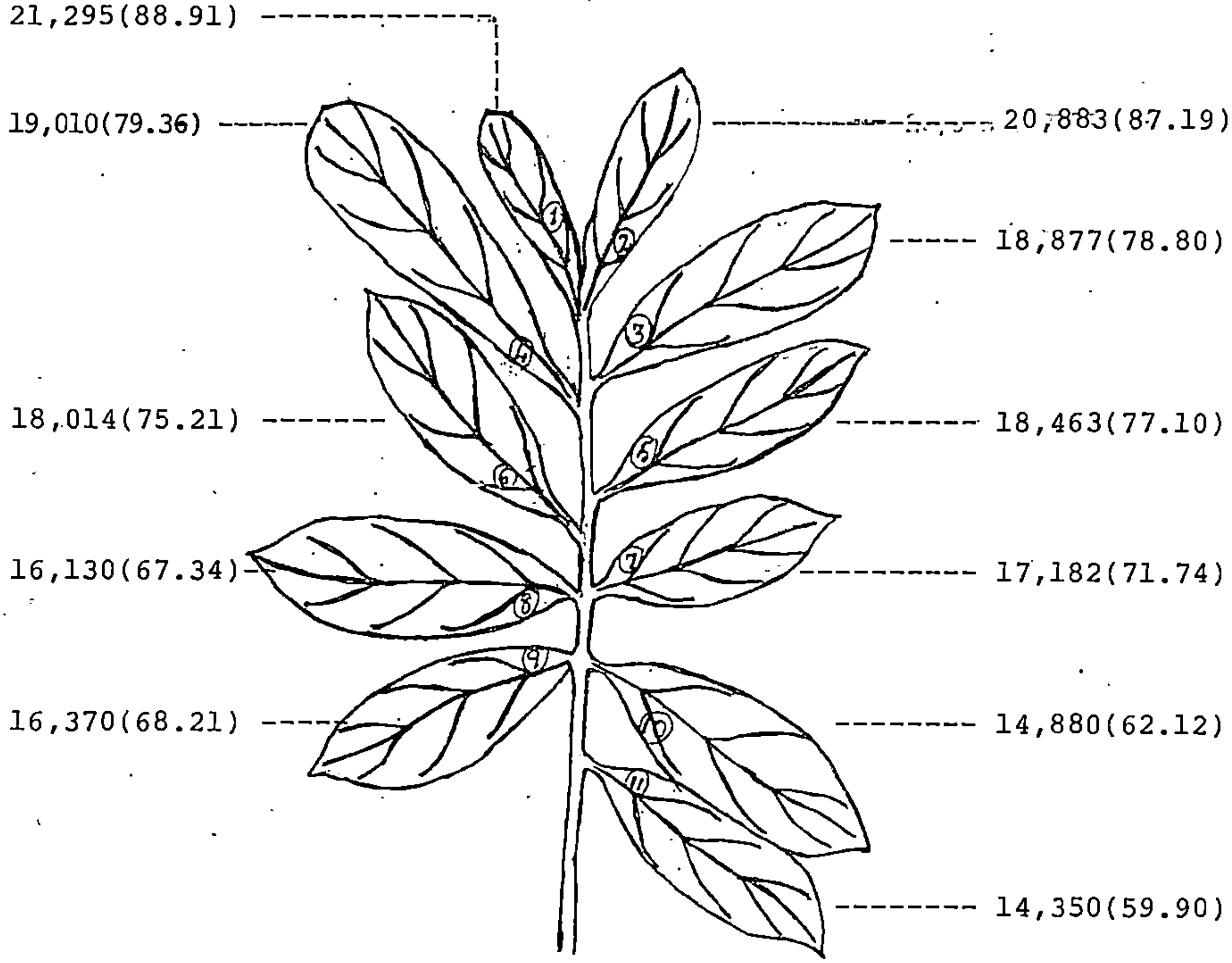


Fig.10. Foliar absorption of ^{14}C-urea (cpm) by cashew seedling in relation to leaf age. (Figures in bracket indicate percentage absorption to total)

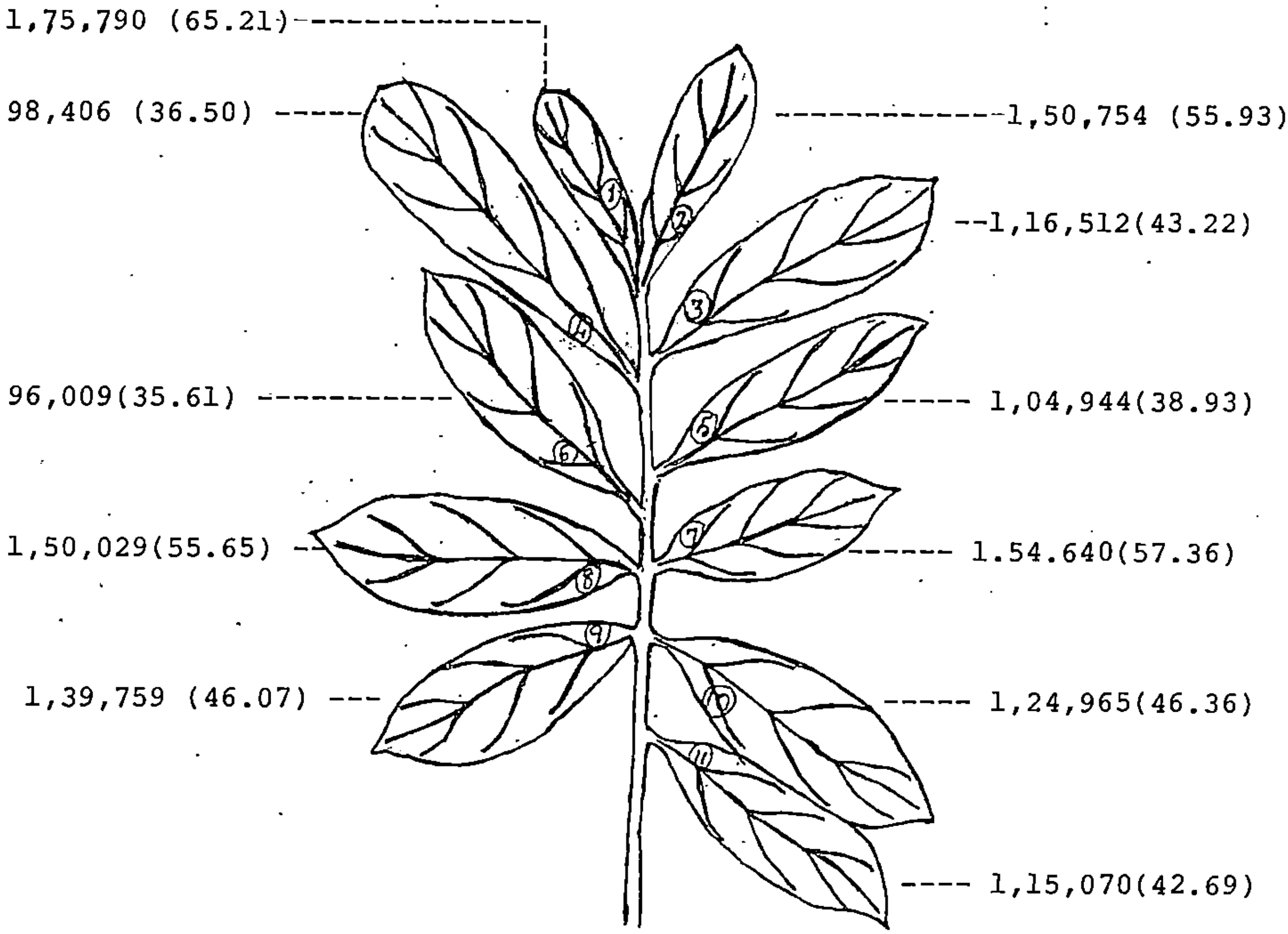


Fig.11. Foliar absorption of ^{32}P (cpm) by cashew seedling in relation to leaf age.(Figures in bracket indicate percentage absorption to total)

absorption of ^{14}C-urea was about 74 per cent, but the absorption of ^{32}P through the leaf was only about 48 per cent.

e. Foliar absorption of ^{14}C-urea in relation to duration of absorption and leaf surface

The amount, percentage and rate of absorption of ^{14}C-urea varied with the duration of absorption, leaf surface and their interaction (Table 7 and Fig. 12, 13, 14). In this experiment, a maximum duration of 168 hours was given for absorption and the amount of absorption increased with increase in the duration upto 120 hours. But the percentage of absorption increased with increase in duration upto a period of seven days. It took about 168 hours to absorb 82.96 per cent of ^{14}C-urea applied on the upper surface, whereas the same amount of absorption was achieved within a period of 48 hours when applied on the lower surface. When considered over a short period of time (24 h), only 36.7 per cent of the urea applied on the upper surface was absorbed, while 80.68 per cent of the urea applied on the lower surface was absorbed within the same period (Fig.13).

The rate of absorption differed considerably between the two surfaces and it was higher through the lower surface (Fig.14). The absorption rate was at its peak

Table 7. Foliar absorption of ^{14}C-urea in relation to duration of absorption and leaf surface

Treatments	Amount absorbed (log cpm)	Per cent absorption	Rate of absorption (log cpm/h)
Duration of absorption			
4 h	3.751 (6393)[h]	15.06[j]	3.149 (1598)[a]
8 ,,	4.015 (12450)[g]	29.33[i]	3.129 (1556)[ab]
12 ,,	4.198 (18000)[f]	42.40[h]	3.119 (1499)[ab]
24 ,,	4.363 (24916)[e]	58.71[g]	2.982 (1038)[b]
48 ,,	4.422 (27636)[de]	65.11[f]	2.741 (576)[c]
72 ,,	4.466 (30142)[cd]	71.00[e]	2.608 (418)[d]
96 ,,	4.506 (32781)[bc]	77.22[d]	2.523 (342)[de]
120 ,,	4.544 (35405)[ab]	83.40[c]	2.465 (295)[ef]
144 ,,	4.567 (37113)[ab]	87.53[b]	2.409 (258)[f]
168 ,,	4.584 (38506)[a]	90.71[a]	2.359 (229)[f]
SEm±	0.024	1.024	0.0359
CD (0.05)	0.0665	2.843	0.0995
Surface			
Upper	4.209 (20126)	47.43	2.613 (477)
Lower	4.475 (32542)	76.66	3.03 (1084)
SEm±	0.011	0.458	0.0161
CD (0.05)	0.030	1.272	0.045
Duration x Surface			
Upper			
4 h	3.537 (3470)[k]	8.17[m]	2.935 (868)[c]
8 ,,	3.780 (6317)[j]	14.88[l]	2.897 (790)[c]
12 ,,	3.973 (9417)[i]	22.18[k]	2.894 (784)[c]
24 ,,	3.191 (15583)[h]	36.73[j]	2.810 (649)[c]
48 ,,	4.292 (19633)[fg]	46.25[i]	2.611 (409)[de]
72 ,,	4.357 (22767)[ef]	53.63[h]	2.500 (316)[efg]
96 ,,	4.412 (25867)[de]	60.93[g]	2.430 (269)[fgh]
120 ,,	4.477 (30030)[c]	70.74[f]	2.398 (250)[fgh]
144 ,,	4.518 (32967)[bc]	77.86[e]	2.360 (229)[gh]
168 ,,	4.547 (35217)[ab]	82.96[d]	2.322 (210)[h]
Lower			
4 h	3.965 (9317)[i]	21.95[k]	3.364 (2329)[a]
8 ,,	4.251 (18583)[gh]	43.77[i]	3.362 (2322)[a]
12 ,,	4.424 (26583)[cde]	62.62[g]	3.345 (2215)[a]
24 ,,	4.535 (34250)[ab]	80.68[d]	3.154 (1427)[d]
48 ,,	4.552 (35640)[ab]	83.96[d]	2.871 (743)[c]
72 ,,	4.574 (37516)[ab]	88.38[c]	2.717 (521)[d]
96 ,,	4.599 (39696)[ab]	93.51[b]	2.616 (414)[de]
120 ,,	4.610 (40780)[ab]	96.06[ab]	2.531 (340)[ef]
144 ,,	4.616 (41259)[a]	97.19[ab]	2.457 (287)[fgh]
168 ,,	4.621 (41796)[a]	98.46[a]	2.396 (249)[fgh]
SEm±	0.034	1.44	0.051
CD (0.05)	0.094	4.021	0.141

Figures in the parentheses denote count in cpm.
Data followed by the same alphabet are not different.

Fig.12 Foliar absorption of ^{14}C - urea by cashew in relation to duration of absorption and leaf surface

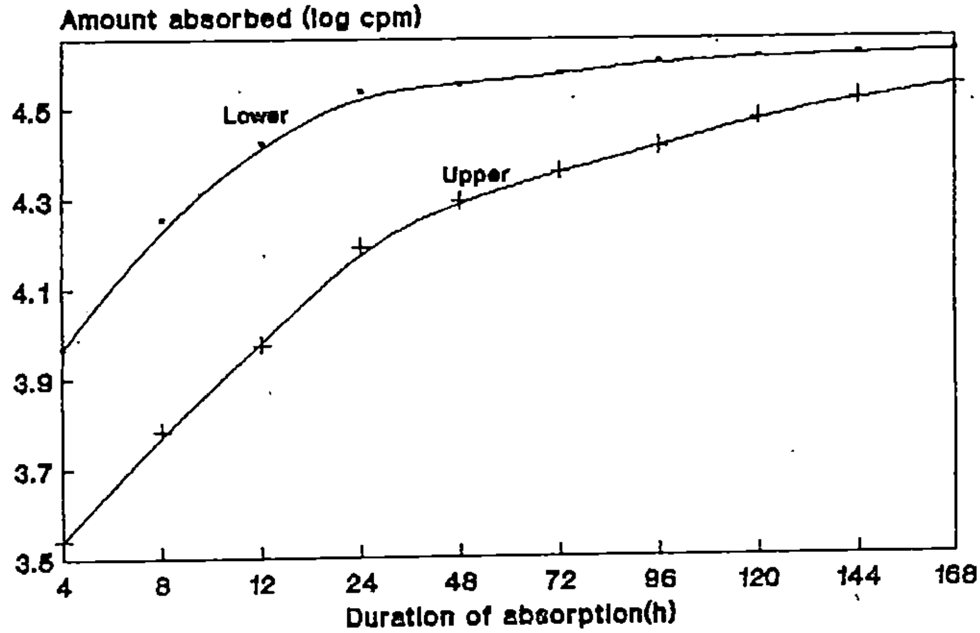


Fig.13 Percentage absorption of foliar applied ^{14}C - urea in relation to duration of absorption & leaf surface

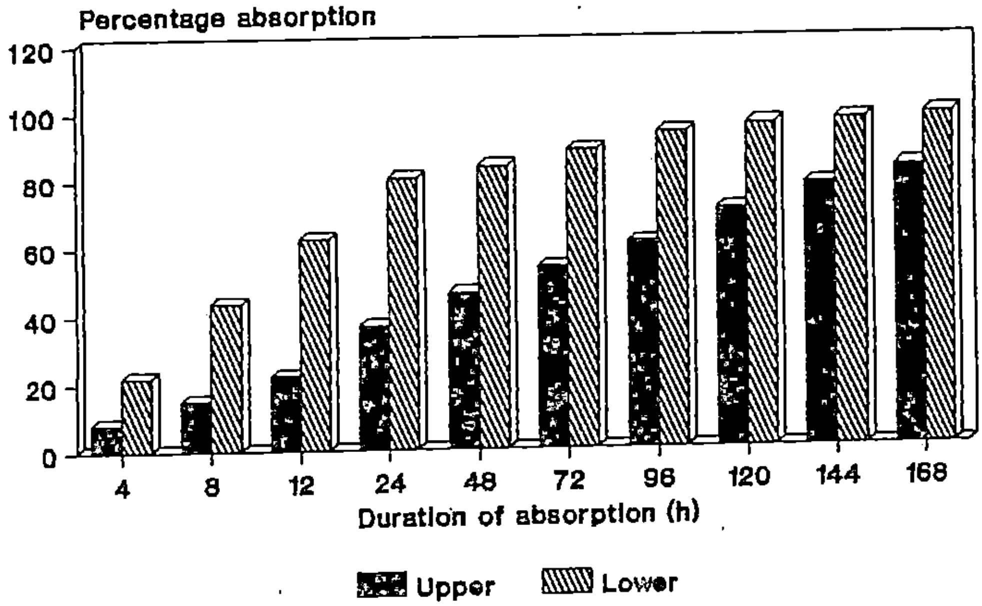


Fig.14 Rate of absorption of ^{14}C - urea by cashew leaves in relation to duration of absorption and leaf surface

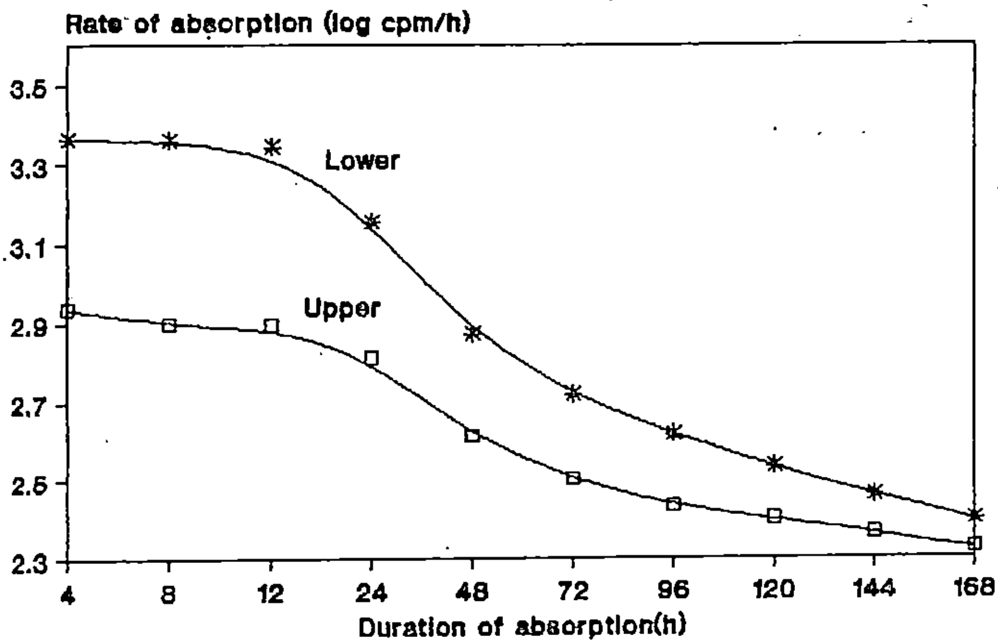
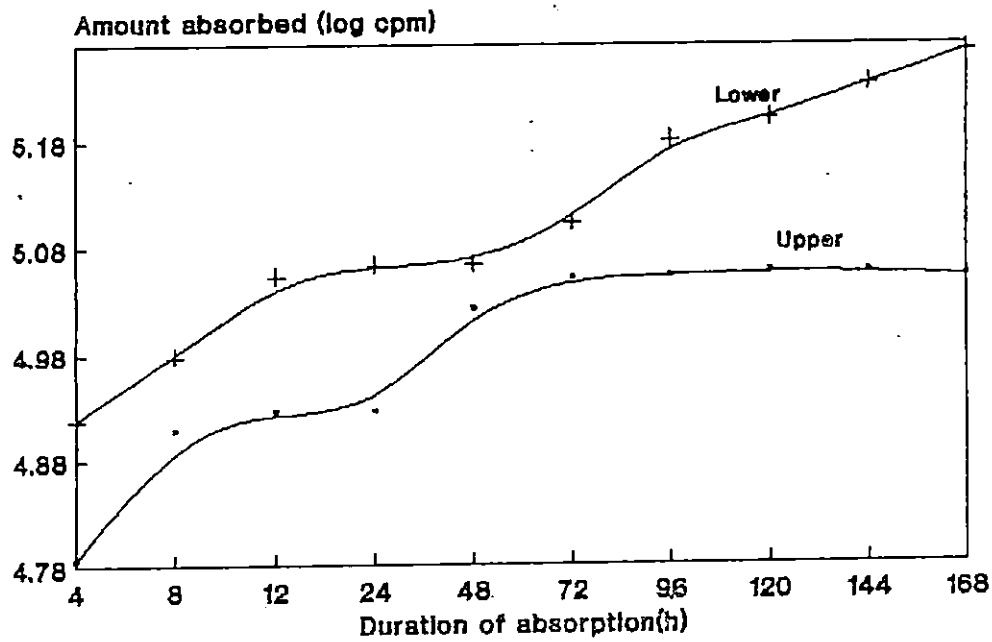


Fig.15 Foliar absorption of ^{32}P by cashew in relation to duration of absorption and leaf surface



initially and the rate declined with increase in the duration of absorption. The rate of absorption was very low beyond an absorption period of 96 hours.

f. Foliar absorption of ^{32}P in relation to duration of absorption and leaf surface

The amount, percentage and rate of absorption of ^{32}P differed with the duration of absorption, leaf surface and their interaction (Table 8 and Fig. 15, 16, 17). In this experiment, a maximum duration of 168 hours was given. The amount of absorption increased with time upto a duration of 96 hours only, while the percentage absorption increased with time upto six days. The amount, per cent and rate of absorption of ^{32}P differed with leaf surface and the absorption was more through the lower surface.

The absorption of ^{32}P applied on the upper surface of leaf increased with time upto a duration of 72 hours only (Fig. 15). The absorption of ^{32}P through the lower surface was larger and faster. It took about 72 hours to absorb 30.2 per cent of the ^{32}P applied on the upper surface, while the same amount of absorption was achieved within a period of 12 hours when applied on the lower surface (Fig. 16).

Table 8. Foliar absorption of ^{32}P in relation to duration of absorption and leaf surface

Treatments	Amount absorbed (log cpm)	Per cent absorption	Rate of absorption (log cpm/h)
Duration of absorption			
4 h	4.851 (72925)[e]	19.53[g]	4.429 (18192)[a]
8 ,,	4.943 (88718)[d]	23.76[f]	4.040 (12248)[b]
12 ,,	4.989 (97267)[c]	26.47[e]	3.910 (8673)[c]
24 ,,	5.002 (102165)[c]	27.37[de]	3.621 (4413)[d]
48 ,,	5.004 (111159)[bc]	29.78[cd]	3.363 (2244)[e]
72 ,,	5.077 (119970)[b]	32.14[c]	3.220 (1723)[f]
96 ,,	5.117 (132786)[ab]	35.57[b]	3.135 (1386)[g]
120 ,,	5.129 (137634)[ab]	36.86[b]	3.050 (1123)[h]
144 ,,	5.145 (142835)[a]	38.26[ab]	2.986 (960)[i]
168 ,,	5.158 (148792)[a]	39.86[a]	2.933 (926)[i]
SEm±	0.023	0.975	0.0233
CD (0.05)	0.063	2.7	0.063
Surface			
Upper	4.985 (98672)	26.52	3.39 (4370)
Lower	5.106 (132178)	35.4	3.511 (6151)
SEm+	0.0104	0.434	0.0104
CD (0.05)	0.028	1.209	0.028
Duration x Surface			
Upper			
4 h	4.785 (61822)[g]	16.56[h]	4.183 (15456)[b]
8 ,,	4.908 (81222)[f]	21.76[g]	4.005 (10153)[c]
12 ,,	4.925 (81250)[f]	22.59[fg]	3.846 (7028)[e]
24 ,,	4.941 (88637)[e]	23.75[fg]	3.567 (3693)[f]
48 ,,	5.023 (105701)[cde]	28.32[e]	3.342 (2202)[h]
72 ,,	5.051 (112425)[cd]	30.12[e]	3.193 (1561)[j]
96 ,,	5.053 (113385)[cd]	30.37[d]	3.071 (1187)[k]
120 ,,	5.057 (114933)[cd]	30.78[d]	2.978 (958)[m]
144 ,,	5.056 (113895)[cd]	30.51[d]	2.898 (791)[ml]
168 ,,	5.052 (113454)[cd]	30.39[d]	2.827 (675)[l]
Lower			
4 h	4.918 (84029)[f]	22.51[fg]	4.316 (22368)[a]
8 ,,	4.978 (96215)[de]	25.77[f]	4.075 (14343)[c]
12 ,,	5.053 (113285)[cd]	30.35[d]	3.974 (10318)[d]
24 ,,	5.063 (115693)[cd]	30.99[d]	3.683 (5133)[d]
48 ,,	5.065 (116618)[cd]	31.24[d]	3.384 (2287)[h]
72 ,,	5.104 (127516)[bc]	34.16[d]	3.246 (1886)[i]
96 ,,	5.181 (152187)[ab]	40.77[c]	3.198 (1585)[j]
120 ,,	5.201 (160334)[a]	42.95[bc]	3.122 (1288)[jk]
144 ,,	5.233 (171774)[a]	46.02[ab]	3.074 (1130)[k]
168 ,,	5.264 (184129)[a]	49.33[a]	3.039 (1096)[k]
SEm+	0.033	1.370	0.033
CD (0.05)	0.091	3.823	0.091

Figures in the parentheses denote count in cpm.
Data followed by the same alphabet are not different.

Fig.16 Percentage absorption of foliar applied ^{32}P in relation to duration of absorption & leaf surface

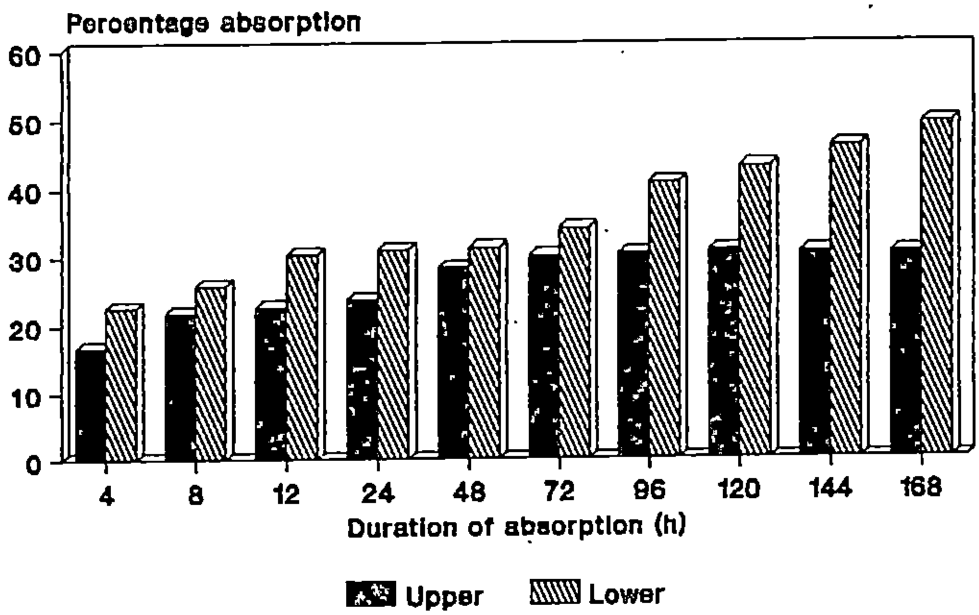
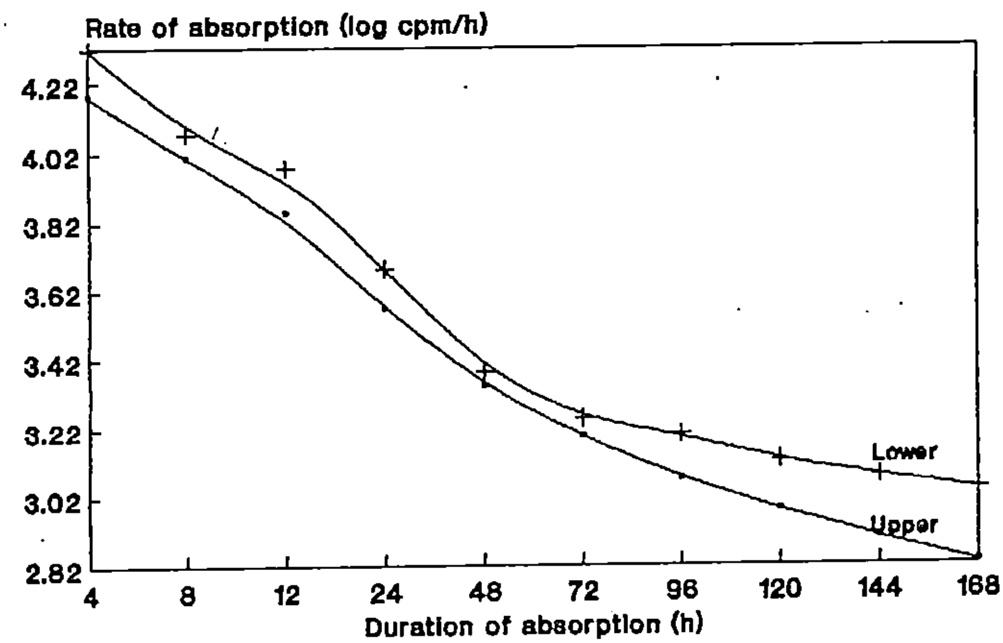


Fig.17 Rate of absorption of ^{32}P by cashew leaves in relation to duration of absorption and leaf surface



g. Diurnal variation in the foliar absorption of ^{14}C-urea

The foliar absorption of ^{14}C-urea with respect to time of application in a day is given in Table 9 and Fig. 18. The foliar absorption of ^{14}C-urea differed with time of application in a day. The amount of absorption and the per cent of absorption of the foliar applied urea reached its peak from 11 00 hours to 14 00 hours. Both in the forenoon (07 00 hours to 11 00 hours) as well as in the afternoon (14 00 hours to 18 00 hours), the absorption was generally low. The highest per cent of absorption (52.68) was observed when urea was applied at 13 00 hours and application of urea at 11 00, 12 00, 13 00 and 14 00 hours resulted in more or less the same amount of absorption.

h. Diurnal variation in the foliar absorption of ^{32}P

The data on the diurnal variation in the foliar absorption of ^{32}P is given in Table 9 and Fig.18. The amount of absorption and the per cent of absorption of ^{32}P reached its peak when ^{32}P was applied at 11 00 hours (27.92 per cent). The absorption was comparatively low in the forenoon from 07 00 hours to 11 00 hours and in the afternoon from 14 00 hours to 18 00 hours. The absorption was the lowest (8.57 per cent) when ^{32}P was applied at 07 00 hours in the morning.

Table 9. Diurnal variation in the foliar absorptioon of ^{14}C-urea and ^{32}P

Time	^{14}C-urea		^{32}P	
	Amount absorbed (log cpm)	Per cent absorption	Amount absorbed (log cpm)	Per cent absorption
7-8 hours	4.178 (15720)^{ab}	37.33^{b}	5.637 (477900)^{c}	8.57^{d}
8-9 ,,	4.269 (18654)^{ab}	44.29^{ab}	5.899 (822034)^{b}	14.70^{c}
9-10 ,,	4.109 (13454)^{b}	31.94^{b}	6.071 (1178233)^{ab}	21.12^{b}
10-11 ,,	4.139 (14054)^{b}	33.37^{b}	6.073 (1184434)^{ab}	21.23^{b}
11-12 ,,	4.327 (21254)^{a}	50.46^{ab}	6.191 (1557834)^{a}	27.92^{a}
12-13 ,,	4.317 (20920)^{a}	49.67^{ab}	5.976 (958634)^{b}	17.18^{bc}
13-14 ,,	4.342 (22187)^{a}	52.68^{a}	5.935 (889367)^{b}	15.94^{bc}
14-15 ,,	4.267 (18587)^{ab}	44.13^{ab}	5.961 (924567)^{b}	16.57^{bc}
15-16 ,,	4.125 (13787)^{b}	32.73^{b}	6.024 (1058367)^{ab}	18.97^{bc}
16-17 ,,	4.32 (20920)^{a}	49.67^{ab}	5.992 (987234)^{b}	17.70^{bc}
17-18 ,,	4.112 (13320)^{b}	31.62^{b}	6.005 (1027434)^{b}	18.42^{bc}
SEm±	0.06	4.89	0.06	1.83
CD (0.05)	0.176	14.329	0.176	5.36

Table 10. Effect of teepol on foliar absorption of ^{14}C-urea and ^{32}P.

Concentration of teepol (%)	^{14}C-urea		^{32}P	
	Amount absorbed (log cpm)	Per cent absorption	Amount absorbed (log cpm)	Per cent absorption
0	4.269 (18583)^{b}	43.77^{b}	6.140 (1380900)^{a}	38.31^{a}
0.05	4.576 (37650)^{a}	88.69^{a}	5.808 (642700)^{b}	17.83^{b}
0.15	4.539 (34583)^{a}	81.47^{a}	5.814 (651466)^{b}	18.07^{b}
SEm±	0.054	2.92	0.037	1.64
CD(0.05)	0.185	10.01	0.127	5.689

Figures in the parantheses denote count in cpm
Data followed by the same alphabet are not significantly different

Fig.18 Diurnal variation in the foliar absorption(%) of ^{14}C -urea and ^{32}P

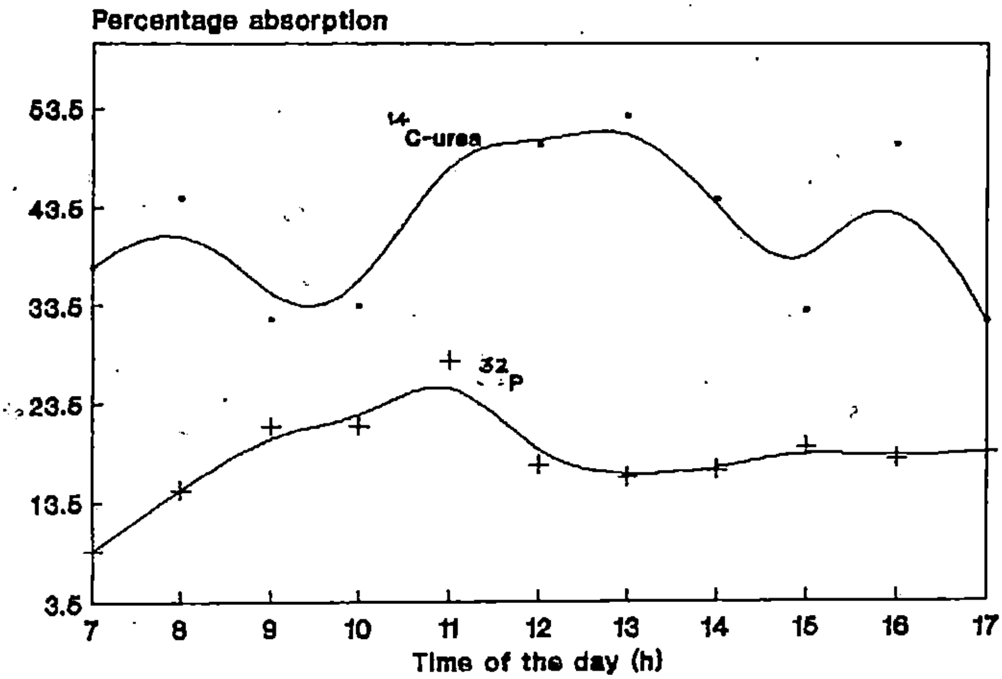
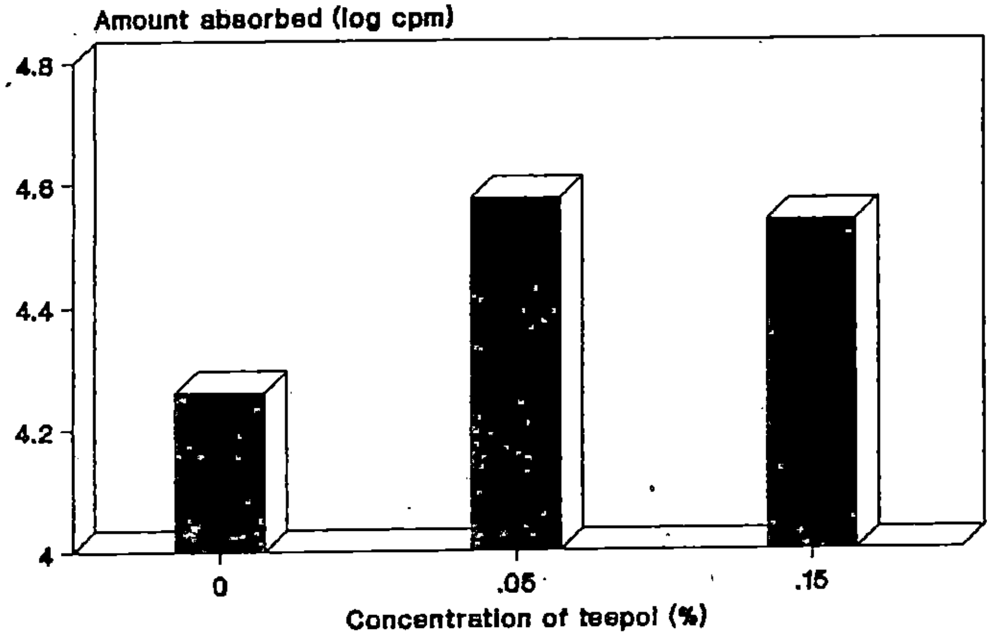


Fig.19 Foliar absorption of ^{14}C - urea in relation to concentration of teepol in the spray solution



i. Effect of teepol on foliar absorption of ^{14}C-urea

The data on the effect of teepol on the foliar absorption of ^{14}C-urea is given in Table 10 and Fig.19, 20. Foliar absorption of ^{14}C-urea varied due to concentrations of teepol in the spray solution. The amount of absorption was the highest when the spray solution contained 0.05 per cent teepol and the absorption did not increase further by increasing the teepol concentration to 0.15 per cent in the spray solution. The percentage of absorption was the highest (88.7 per cent) when the foliar spray was given with 0.05 per cent teepol and its effect was on par with that of teepol concentration of 0.15 per cent (81.5 per cent). When teepol was not used in the spray solution, the percentage of absorption was only 43.8 per cent.

j. Effect of teepol on foliar absorption of ^{32}P

Both the amount of absorption as well as the percentage of absorption of foliar applied ^{32}P decreased due to inclusion of teepol in the spray solution (Table 10).

k. Monthly variation on foliar absorption of ^{14}C-urea in relation to leaf age and leaf surface.

The amount of absorption of ^{14}C-urea did not differ due to age of flush (Table 11). The urea absorption was more through lower surface than the upper one.

Fig.20 Percentage absorption of foliar applied ^{14}C - urea in relation to concentration of teepol in the spray

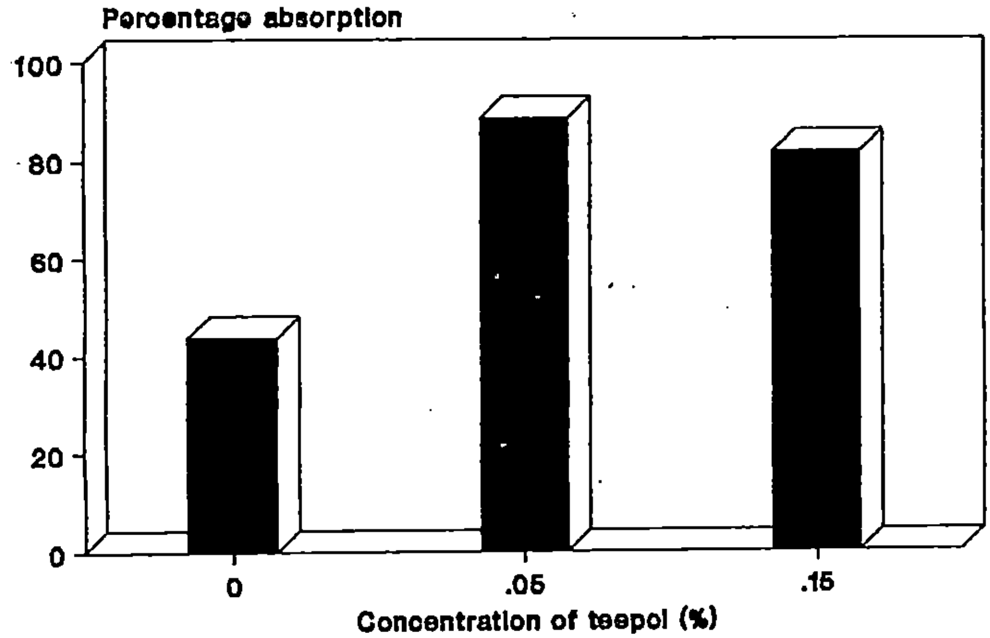


Fig.21 Quantity (log cpm) and rate (log cpm/h) of absorption of ^{14}C -urea through roots of cashew seedlings

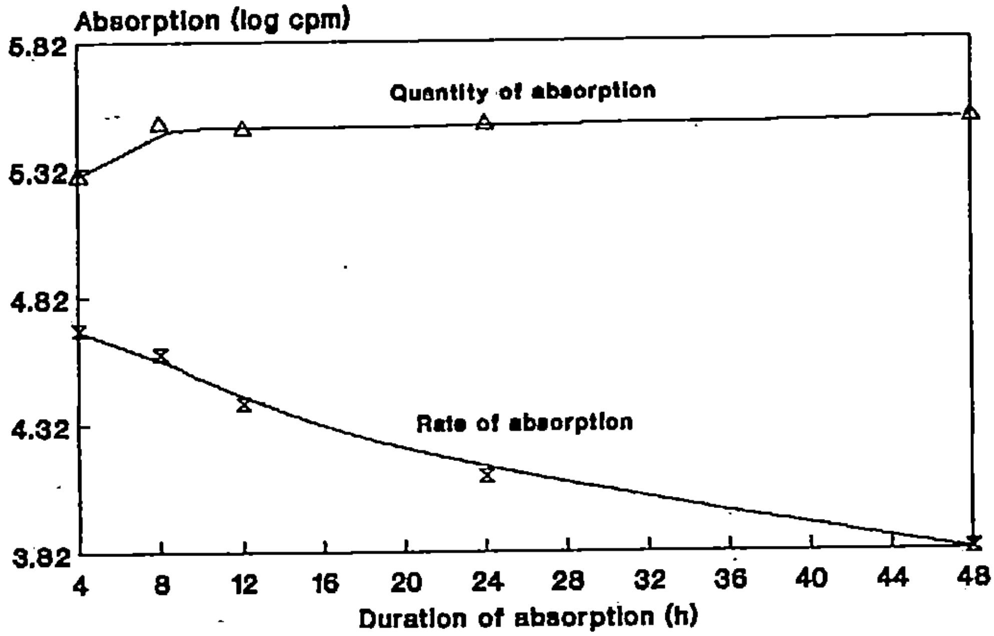


Table 11. Foliar absorption of ^{14}C-urea in relation to age of flush and leaf surface during different months

Treatments	February	March
	Amount absorbed (log cpm)	Amount absorbed (log cpm)
Leaf age		
Latest flush-terminal leaves	4.499 (31937)	4.582 (38345)
latest flush-central leaves	4.537 (34715)	4.564 (36767)
Latest flush-basal leaves	4.536 (34508)	4.551 (35634)
SEm±	0.016	0.011
CD (0.05)	NS	NS
Leaf surface		
Upper	4.485 (30745)	4.544 (35033)
Lower	0.564 (36693)	4.588 (38796)
SEm±	0.013	0.009
CD (0.05)	0.040	0.028

Figures in parentheses denote count in cpm

The percentage absorption did not differ due to age of flush (Table 12). But it varied with leaf surface and month of application. The percentage absorption was the highest through the lower surface. Between the two months in which the studies were conducted (February and March), the absorption was highest (88.94 per cent) during March (Table 12). The interaction between age of flush and month of application was significant and the highest absorption (92.37 per cent) was noticed with the youngest leaves (terminal leaves of latest flush) during March.

1. Monthly variation on foliar absorption of ^{32}P in relation to leaf age and leaf surface.

The amount of absorption varied with age of flush and this was noticed during February and March, but not in December (Table 13). The mature leaves of the latest flush absorbed more ^{32}P compared to the younger ones. The amount of absorption of ^{32}P differed due to leaf surface and it was the highest when applied on the lower surface

The percentage absorption differed due to months of application (December, February and March), age of flush, leaf surface and interaction between the month of application and leaf age (Table 12). Among the three months tried, the foliar absorption of ^{32}P was the highest (70.80 per cent) during December and lowest during February (41.01

Table 12. Variation in the per cent absorption of ^{14}C-urea and ^{32}P due to different months of application, age of flush andleaf surface.

Treatments	Percentage absorption	
	^{14}C-urea	^{32}P
Months		
December (M_1)	---	70.80^{a}
February (M_2)	79.46	41.01^{c}
March (M_3)	88.94	66.72^{b}
SEm±	1.001	1.019
CD (0.05)	3.015	2.82
Age of flush		
Latest flush-terminal leaves (A_1)	83.83	56.10^{b}
Latest flush-central leaves (A_2)	85.19	60.36^{a}
Latest flush-basal leaves (A_3)	83.59	62.08^{a}
SEm±	1.16	1.019
CD (0.05)	NS	2.82
Leaf surface		
Upper	78.39	54.53
Lower	89.98	64.49
SEm±	1.001	0.832
CD (0.05)	3.015	2.3
Month and Age		
M_1 A_1	----	70.37^{ab}
M_1 A_2	----	67.95^{b}
M_1 A_3	----	74.09^{a}
M_2 A_1	75.29^{d}	36.84^{e}
M_2 A_2	81.78^{cd}	43.38^{d}
M_2 A_3	81.31^{cd}	42.82^{d}
M_3 A_1	92.37^{a}	61.07^{c}
M_3 A_2	88.59^{ab}	69.75^{ab}
M_3 A_3	85.86^{bc}	69.33^{ab}
SE m±	1.79	1.764
CD (0.05)	5.22	4.78

Data followed by the same alphabet are not significantly different.

Table 13. Foliar absorption of ^{32}P in relation to age of flush and leaf surface during different months

Treatments	December	February	March
	Amount absorbed (log cpm)	Amount absorbed (log cpm)	Amount absorbed (log cpm)
Leaf age			
Latest flush-terminal leaves	4.645 (44600)	6.391 (2474954)[b]	6.555 (4545867)[b]
latest flush-central leaves	4.655 (46512)	6.462 (2914034)[a]	6.712 (5191400)[a]
Latest flush-basal leaves	4.707 (51319)	6.455 (2876429)[a]	6.711 (5160466)[a]
SEm±	0.0193	0.019	0.009
CD (0.05)	NS	0.058	0.028
Leaf surface			
Upper	4.649 (44679)	6.404 (2554667)	6.65 (4483499)
Lower	4.698 (50442)	6.469 (2955610)	6.736 (5563500)
SEm±	0.014	0.015	0.007
CD (0.05)	0.39	0.047	0.022

Figures in parentheses denote count in cpm

Data followed by the same alphabet are not significantly different.

per cent). Among the three leaf ages studied, the percentage absorption was the highest with the older leaves (basal leaves of latest flush). Percentage absorption differed due to leaf surface and it was higher through the lower surface.

The highest percentage absorption of ^{32}P (74.09 per cent) was observed during December with basal leaves of the latest flush and lowest absorption during February with terminal leaves of the latest flush (36.84 per cent).

Part III. Root absorption of ^{14}C-urea and ^{32}P by cashew seedlings

a. Root absorption of ^{14}C-urea

Cashew seedlings absorbed molecular urea through roots and the amount of absorption increased initially and stabilised thereafter (Table 14). Rate of absorption was the highest initially and the rate declined drastically with the increase in the duration of absorption and it was lowest with the highest duration (48 hours) given in the experiment (Fig. 21).

The percentage of absorption reached as high as 92.41 per cent within 8 hours time and it did not increase substantially by increasing the duration of absorption to

Table 14. Absorption of ^{14}C-urea and ^{32}P through roots of three months old cashew seedlings in relation to duration of absorption

Duration of absorption (h)	^{14}C-urea			^{32}P		
	Amount absorbed (log cpm)	Percent absorption	Rate of absorption (log cpm/h)	Amount absorbed (log cpm)	Percent absorption	Rate of absorption (log cpm/h)
4	5.291 (196000)^{b}	58.96^{b}	4.689 (49000)^{a}	6.162 (1466625)^{b}	41.58^{b}	5.560 (366656)^{a}
8	5.494 (312812)^{a}	92.41^{a}	4.591 (39101)^{b}	6.320 (2097563)^{a}	59.15^{a}	5.417 (262195)^{b}
12	5.475 (300062)^{a}	93.50^{a}	4.396 (25005)^{c}	6.299 (2008188)^{a}	59.43^{a}	5.220 (167349)^{c}
24	5.488 (308062)^{a}	93.50^{a}	4.108 (12835)^{d}	6.300 (1997000)^{a}	58.46^{a}	4.920 (80575)^{d}
48	5.505 (322250)^{a}	94.59^{a}	3.823 (6713)^{e}	6.322 (2102250)^{a}	62.58^{a}	4.641 (44380)^{e}
SEm$\pm$	0.02	2.25	0.02	0.02	2.49	0.02
CD (0.05)	0.06	4.58	0.06	0.06	6.84	0.06

Figures in the parentheses denote count in cpm

Data followed by the same alphabet are not significantly different.

any further. Within a period of 4 hours, 58.96 per cent of applied urea was absorbed (Fig.22).

b. Root absorption of ^{32}P

Cashew seedlings absorbed ^{32}P through roots and the amount of absorption increased initially (upto 8 hours) and stabilised thereafter (Table 14). Rate of absorption was high when the duration of absorption was small and the rate declined drastically with the increase in the duration of absorption (Fig. 23). The rate of absorption of ^{32}P was lowest with the highest duration (48 hours).

The percentage of absorption reached as high as 59.15 per cent within 8 hours time and it did not increase substantially. Within a period of 4 hours, 41.58 per cent of applied ^{32}P was absorbed (Fig. 22)

The root absorption differed with the nutrient species fed through the solution. While cashew seedlings absorbed 94.59 per cent of ^{14}C-urea in 48 hours period, it absorbed ^{32}P only to the tune of 62.58 per cent in the same period.

Comparison of root absorption (from solution culture) with foliar absorption showed that root absorption from solution was considerably more than foliar absorption in respect of ^{14}C-urea as well as ^{32}P (Table 15). The difference between root absorption and foliar absorption of

Fig.22 Percentage absorption of ^{14}C-urea and ^{32}P through roots of 3 months old cashew seedlings

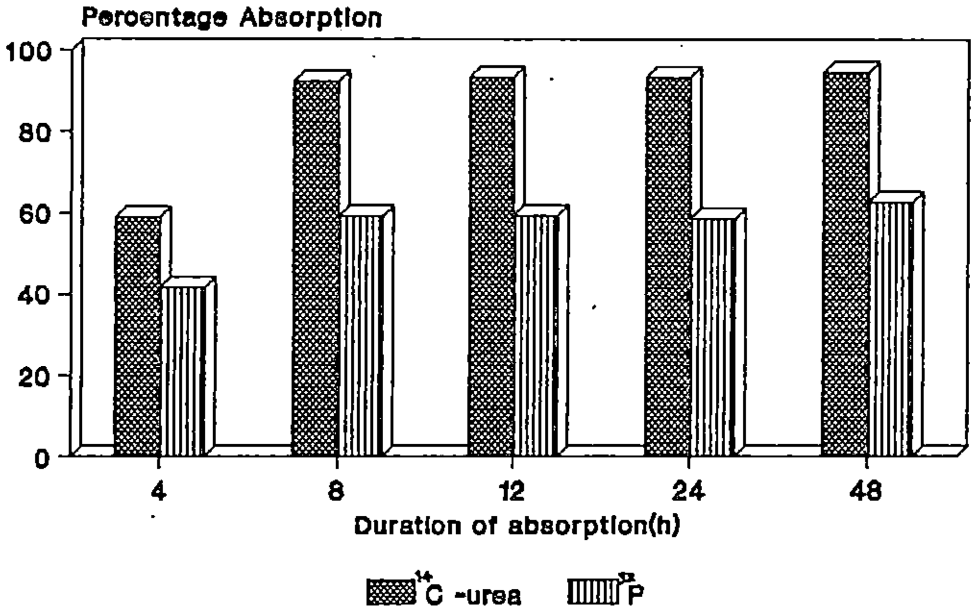


Fig.23 Quantity (log cpm) and rate (log cpm/h) of absorption of ^{32}P through roots of cashew seedlings

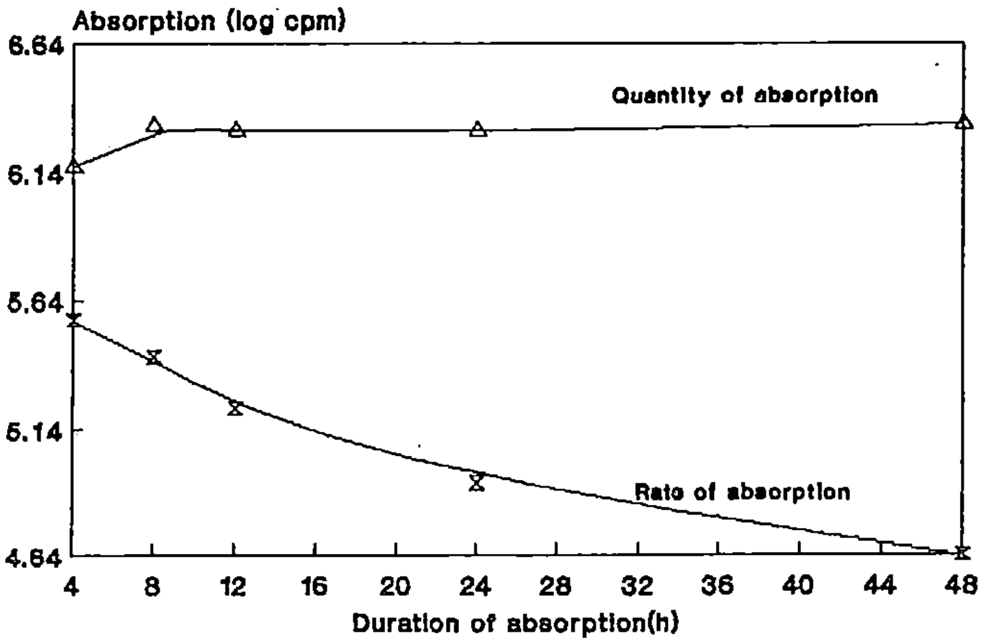


Table. 15 Comparsion between foliar absorption (lower surface) and root absorption of ^{14}C-urea and ^{32}P

Duration (h)	Percentage absorption			
	^{14}C-urea		^{32}P	
	Root	Foliage	Root	Foliage
4	58.96	21.95	41.58	22.51
8	92.41	43.77	59.15	25.77
12	93.50	62.62	59.43	30.35
24	93.50	80.68	58.46	30.99
48	94.50	83.96	62.58	31.24
(Mean)	86.57	58.59	56.24	28.17

Based on data given in Table 7, 8 and 14.

^{14}C-urea was larger during initial periods of absorption upto 12 hours. This difference was narrowed down due to increase in absorption time in the case of urea (Fig. 24). But in the case of ^{32}P, root absorption from solution culture continued to be more than foliar absorption irrespective of duration of absorption (Fig. 25).

Part IV. Studies on leaf anatomy in relation to foliar absorption

a. Cuticle thickness

The cuticle thickness varied with leaf age and it was higher in the older leaves compared to the younger ones (Table 16 and Plate 2). The cuticle of the older leaves (18 weeks old) was 5.98 µ thick, while the cuticle of the younger leaves (one week old) was only 3.33 µ in thickness.

There was considerable difference in the thickness of the cuticle of the upper and lower surfaces (Plate 3). The upper leaf surface had thicker cuticle (5.25 µ), while the cuticle of lower surface was thin (3.87 µ).

The interaction between leaf age and leaf surface on cuticle thickness was also significant. The lower surface of younger leaves had thinner cuticle (2.79 µ) and the upper surface of older leaves had thicker cuticle (6.54 µ).

Fig.24 Variation in foliar absorption and root absorption of ^{14}C - urea by cashew seedlings

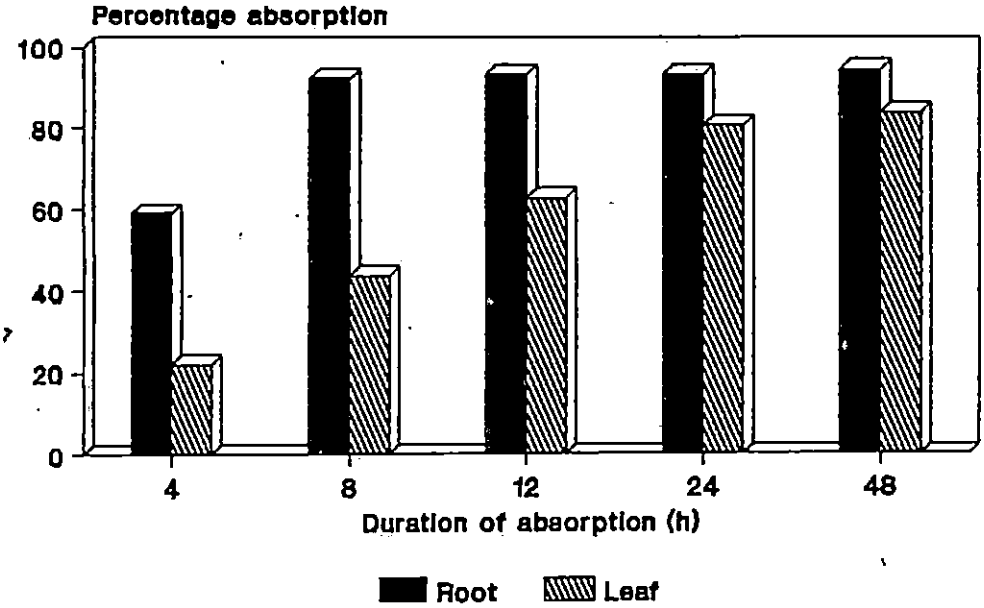


Fig.25 Variation in foliar absorption and root absorption of ^{32}P by cashew seedlings

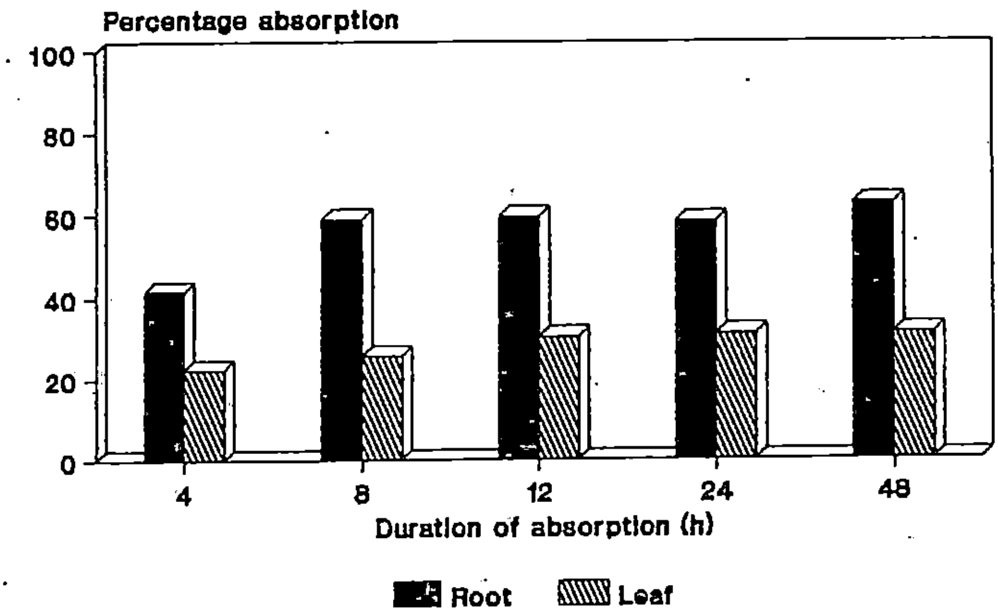
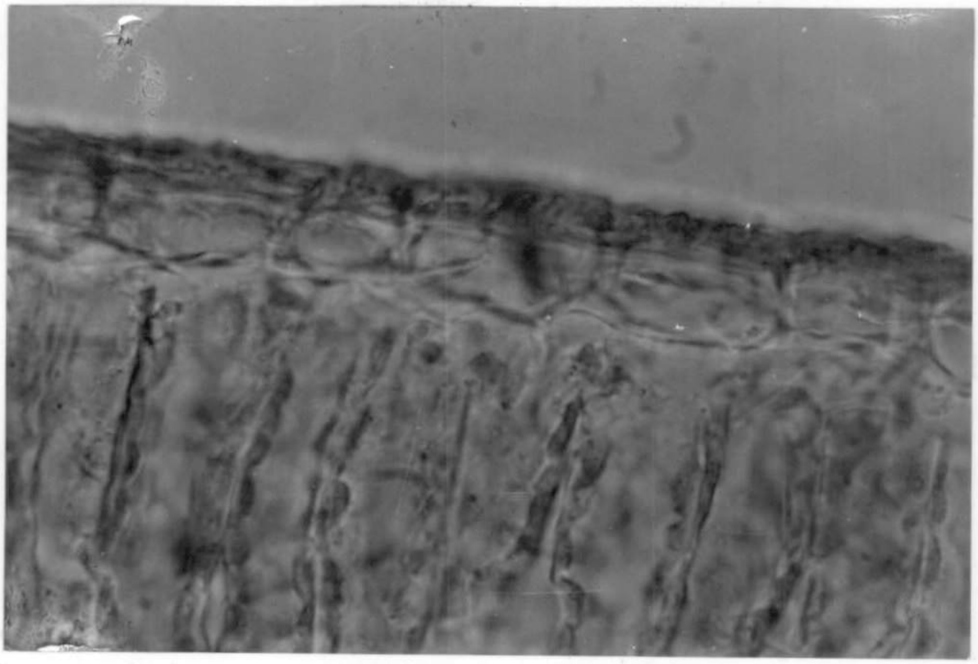


Table 16. Cuticle thickness of cashew leaf in relation to leaf age and leaf surface.

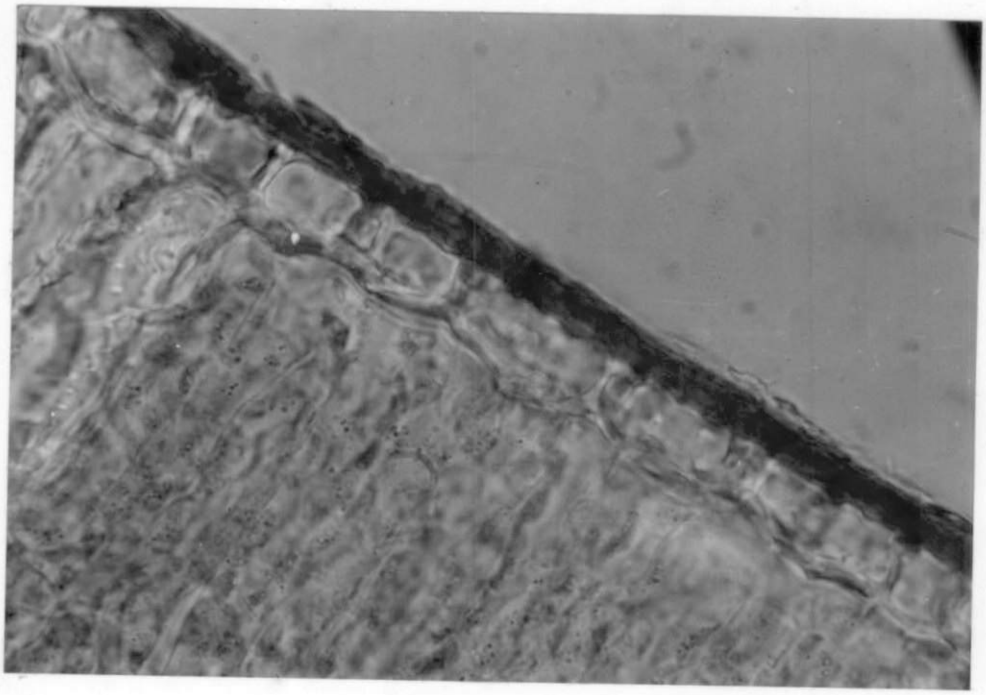
Treatements		Cuticle thickness (μ)
Leaf age		
Latest flush-terminal leaves		3.33[c]
Latest flush-basal leaves		4.36[b]
Leaves of the previous season flush		5.98[a]
SEm±		0.095
CD (0.05)		0.262
Leaf surface		
Upper		5.25
Lower		3.87
SEm±		0.077
CD (0.05)		0.214
Ages Vs. Surface		
Latest flush-terminal leaves-	upper	3.88[c]
,, ,,	lower	2.79[d]
Latest flush-basal leaves-	upper	5.33[b]
,, ,,	lower	3.93[c]
Leaves of the previous season fush-	upper	6.54[a]
,, ,,	lower	5.41[b]
SEm±		0.134
CD (0.05)		0.371

Data followed by the same alphabet are not significantly different.

Plate 2. Photomicrographs showing the cuticle thickness (upper surface) of cashew leaves in relation to leaf age (960 x).

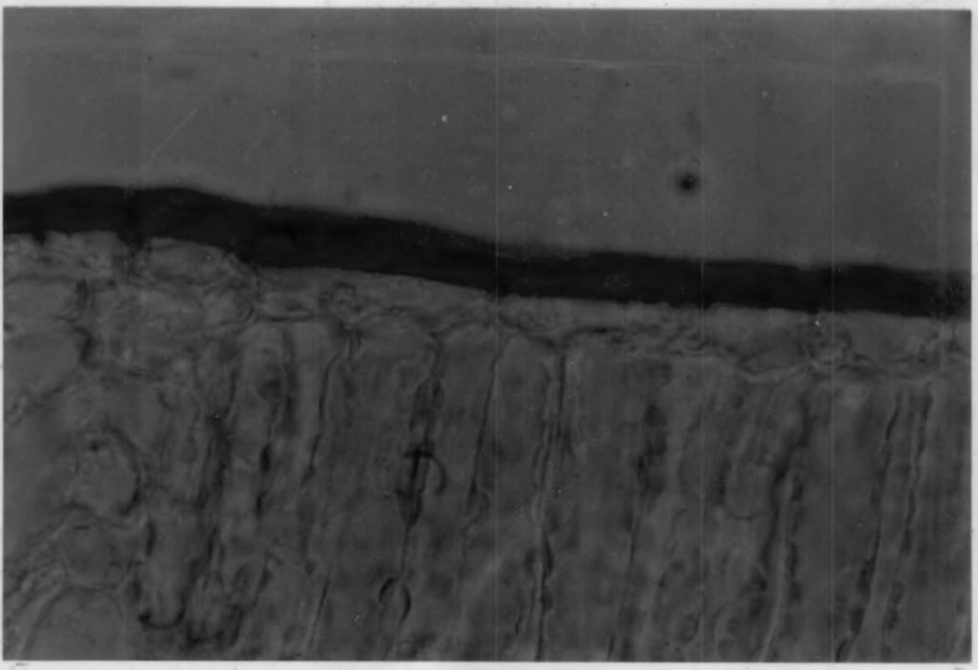


6 week old leaf
Mean thickness: 5.33 μ

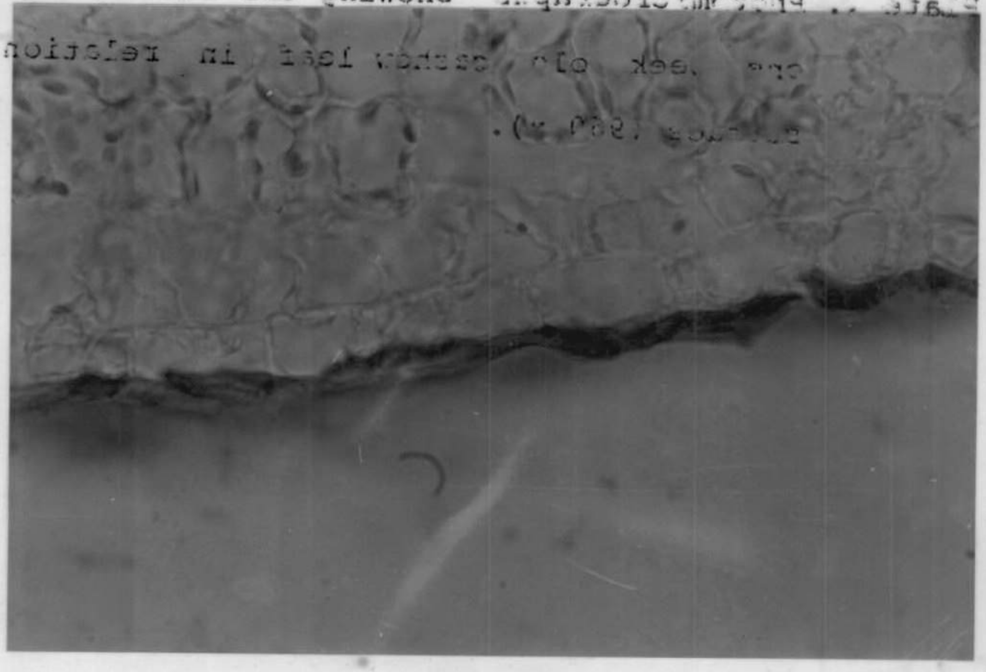


18 week old leaf
Mean thickness: 6.54 μ

Plate 3. Photomicrographs showing the cuticle thickness of one week old cashew leaf in relation to leaf surface (960 x).



Upper surface
Mean thickness: 3.88 µ



Lower surface
Mean thickness: 2.79 µ

b. Stomatal index

The stomatal index was recorded for the upper and lower surface of leaves (Table 17). Stomata was found only on the lower surface of the cashew leaves (Plate 4). The number of stomata per unit leaf area differed considerably due to leaf age (Plate 5). The stomatal index was highest (566 mm^{-2}) in the younger leaves (one week old).

Part V. Canopy analysis in cashew.

A six year old cashew (var. Anakkayam-1) tree contains a total leaf area of 54.15 m^2 on its crown during its flushing phase (Table 18). The leaves of latest flush accounts for 80 per cent of the total leaf area in the crown.

Table 17. Stomatal index of cashew leaf in relation to leaf age and leaf surface.

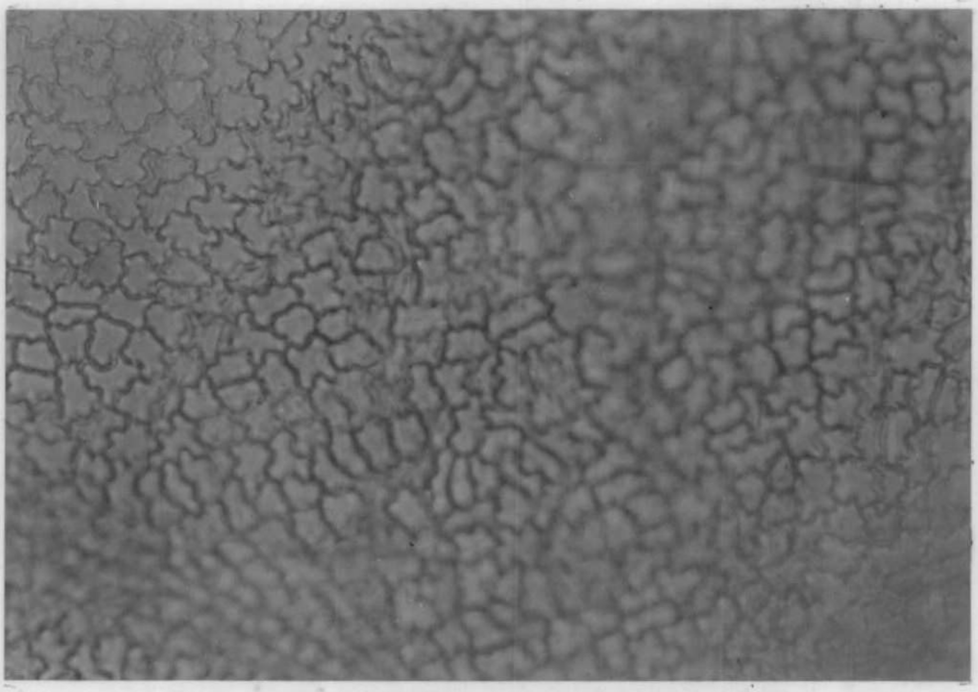
Treatement	Stomatal No.mm^{-2}	
	Lower	Upper
Latest flush-terminal leaves	566[a]	0
Latest flush-basal leaves	412[c]	0
Leaves of the previous season flush	479[b]	0
SEm$\pm$	16.52	
CD (0.05)	45.78	

Table 18. Leaf area of a six year old cashew (var. Anakkayam- I) tree in relation to leaf age during flushing phase (November)

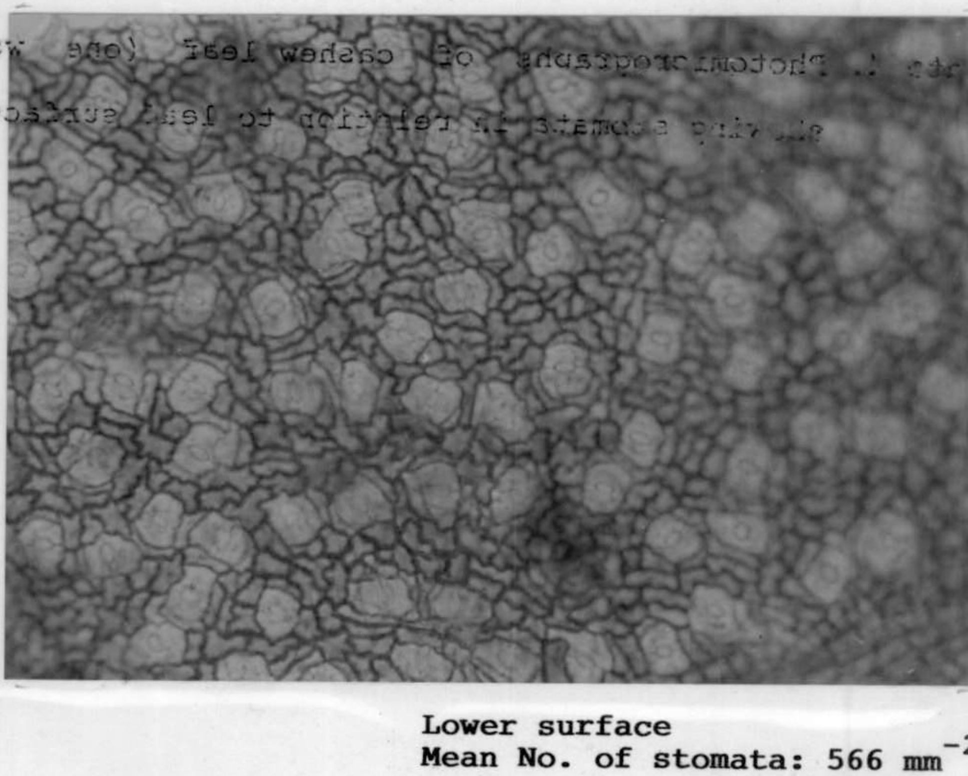
Leaf age	Leaf area m^2	Percentage of leaf area
Latest flush-terminal leaves	8.04	14.80
Latest flush-central leaves	19.04	35.20
Llatest flush-basal leaves	15.85	29.20
Previous season flush	10.63	19.62
One year old flush	0.59	1.18
Total	54.15	100.00

Data followed by the same alphabet are not significantly different.

Plate 4. Photomicrographs of cashew leaf (one week old) showing stomata in relation to leaf surface (158 x).

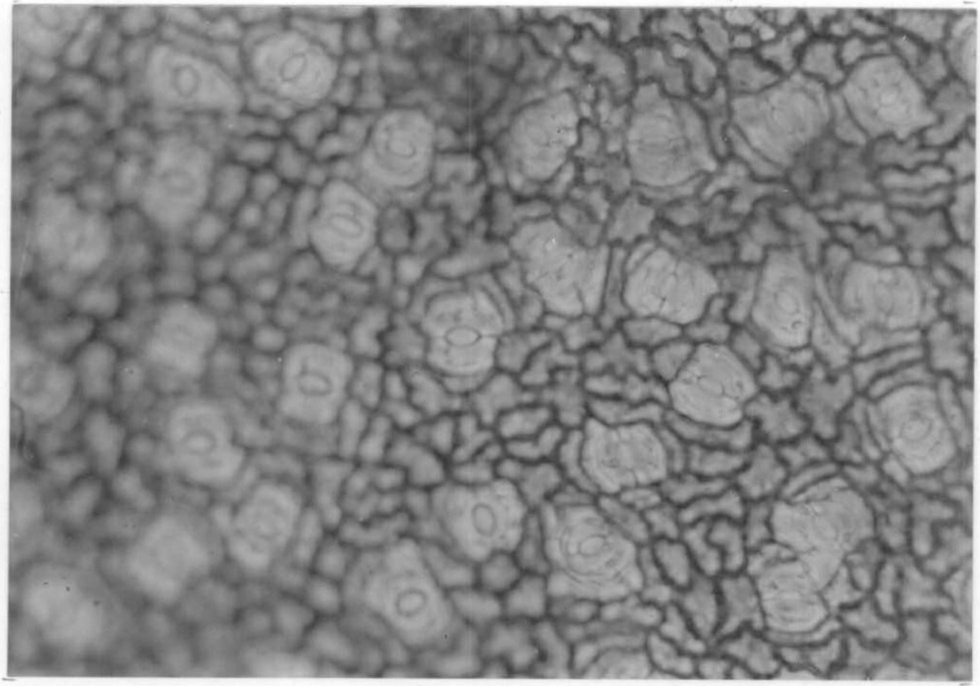


Upper surface
(No stomata)

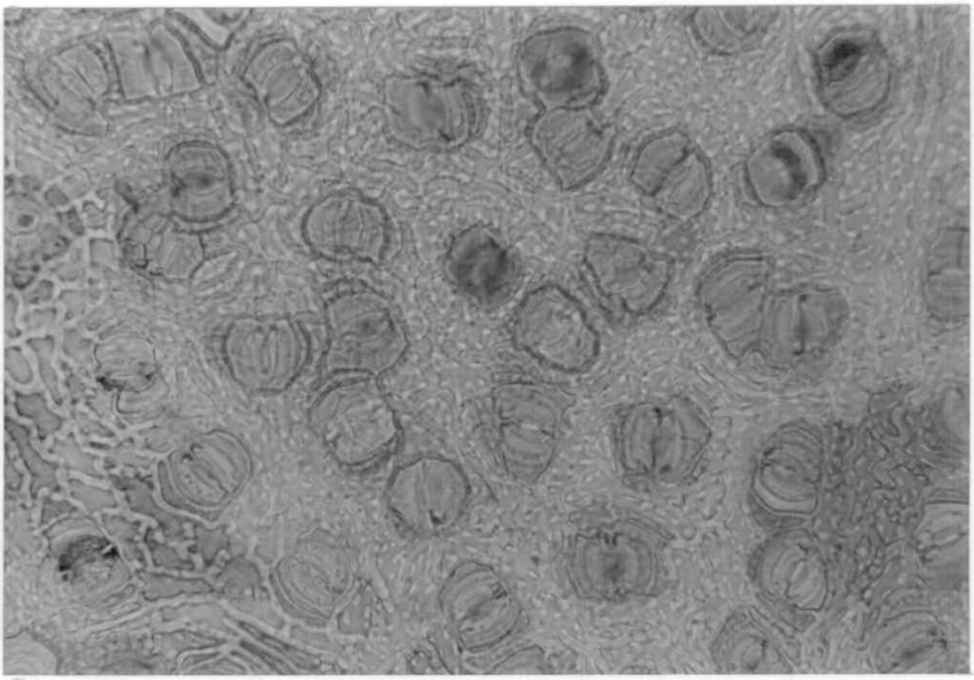


Lower surface
Mean No. of stomata: 566 mm^{-2}

Plate 5. Photomicrographs showing stomatal index of cashew leaves (lower surface) in relation to leaf age (240 x).



One week old leaf
Mean stomatal index: 566 mm^{-2}



18 week old leaf
Mean stomatal index: 479 mm^{-2}

Discussion

DISCUSSION

The results of the various experiments conducted during the course of investigation are discussed below:

Part I. a. Experiment to standardise the leaf age and leaf surface to study the foliar absorption.

Using ^{32}P, an experiment was conducted to study the foliar absorption in relation to leaf surface (upper and lower) and leaf position (second and seventh leaf from the top). There were 10 leaves on the seedling at the time of the experiment. The younger leaves (second leaf from the top) absorbed more ^{32}P compared to the older ones. Similarly the absorption was more through the lower surface of the leaves than through the upper surface (Table 1). This experiment was conducted to choose an efficient leaf and an appropriate leaf surface for conducting further studies on the various aspects of foliar absorption of nutrients by cashew.

Based on these results, the lower surface of the leaf from the top was chosen for detailed study on factors affecting foliar absorption of nutrients in cashew.

b. Method to study the foliar absorption of ^{14}C-urea and ^{32}P

The main objective of the experiment was to develop a method suitable for quantifying the absorption of foliar

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Based on these results, the lower surface of the leaf from the top was chosen for detailed study on factors affecting foliar absorption of nutrients in cashew.

b. Method to study the foliar absorption of ^{14}C-urea and ^{32}P

The main objective of the experiment was to develop a method suitable for quantifying the absorption of foliar applied ^{14}C-urea and ^{32}P by cashew seedlings. A sequential washing technique of the treated leaf, involving eight washings, each with 50 ml of 2 per cent teepol was attempted to quantify the adsorbed nutrient.

The first washing contained 69.01 and 62.17 per cent of the adsorbed ^{14}C-urea and ^{32}P respectively (Table 2 and Fig. 6, 7). The content of the adsorbed nutrients in the subsequent washings were decreasing rapidly and it was negligible with the increase in the number of washings. About 94.6 per cent of the adsorbed ^{14}C-urea and 90.02 per cent of the adsorbed ^{32}P could be removed by four washings in sequence. Hence, a sequential washing programme involving four washings using 50 ml of 2 per cent teepol was considered as reasonable for quantifying the adsorbed ^{14}C-urea and ^{32}P on cashew leaves.

Many workers in the past have used this leaf washing technique in apple (Cook and Boynton, 1952 and Shim et al., 1972), banana (Freiberg and Payne, 1957), sunflower (Wilson and McKell, 1961), beans (Jyung and Wittwer, 1964), soyabean (Ahlgren and Sudia, 1967) and maize (Datta and Vyas, 1967) to quantify the adsorbed nutrients in foliar nutrition studies.

Part II. Factors affecting foliar absorption.

One of the main objectives of the present investigation was to identify the factors affecting foliar absorption of ^{14}C-urea and ^{32}P by cashew. A series of experiments have been conducted to study the influence of leaf age, leaf surface, duration allowed for absorption, time of the day, inclusion of surfactant and month of application on foliar absorption. The results are discussed below.

a. Foliar absorption of ^{14}C-urea and ^{32}P by cashew seedlings in relation to leaf age and leaf surface.

The amount and percentage absorption (Table 3) of ^{14}C-urea was higher through the lower surface than through the upper one. The percentage absorption through the lower surface was 84 per cent, while the absorption through the upper surface was only to the extent of 61 per cent. The study clearly indicates the greater absorption efficiency of the lower surface of the leaf than the upper one.

Many researchers in the past have reported the larger absorption of nutrients through the lower surface of the leaf in apple (Ginsberg, 1930; Cook and Boynton, 1952; Rodney, 1952 and Goodman and Addy, 1962), banana (Freiberg and Payne 1957) and Peach (Bukovac _et al_., 1979).

Sargent and Blackman (1970) reported that the thicker cuticle on the upper surface of the leaves of *Phaseolus vulgaris* was a major barrier to the foliar penetration of nutrients. Stomata plays a major role in the absorption of foliage applied chemicals (Franich *et al*., 1977). Guard cells play a special role in the foliar absorption of nutrients as these cells are equipped with more ectodesmata than other areas of the leaf (Nagarajah, 1978). Kallarackal and Somen (1992) reported that in cashew, stomata are present only on the lower surface of the leaf.

In this experiment the absorption of foliar applied urea was found to be the highest with the young leaves at the terminal end and the absorption decreased with increase in leaf age (Table 5 and Fig. 10). Both the amount and percentage absorption were high (75 to 89 per cent) in the top six leaves of the seedlings, low in the basal leaves and least in the lowest leaf (59.9 per cent). Inhibition of absorption with increase in leaf age had been reported in apple (Cook and Boynton, 1952), coffee, cocoa and banana (Cain, 1956), peach (Bukovac, 1965) and pear (Greene and Bukovac, 1971). The deposition of epicuticular wax on the outer surface of the cuticle increased with leaf development (Bukovac *et al*., 1979).

In the present investigation, it was also attempted to study the leaf anatomy of cashew in relation to leaf age. (please see Part IV). The data on cuticle thickness and stomatal index (Table 16 and 17) explain the differential absorption of nutrients due to leaf surface.

The amount and percentage absorption of foliar applied ^{32}P were more through the lower surface of the younger leaves (Table 4, 5 and Fig.11). The young leaves at the terminal end absorbed about 55.93 to 65.2 per cent of the applied ^{32}P, but the older leaves at the bottom could absorb only 42.69 to 46.07 per cent. The results clearly indicate the efficiency of younger leaves in ^{32}P absorption compared to the older ones.

The reasons explained earlier for the larger absorption of ^{14}C-urea through the lower surface of leaves hold good for ^{32}P as well. Greater absorption of foliar applied phosphorus by younger leaves compared to the older ones have been reported in apple (Fischer and Walker, 1955) soybean (Ahlgren and Sudia, 1967) and maize (Datta and Vyas, 1967).

An attempt was also made to compare the percentage absorption of ^{14}C-urea and ^{32}P by cashew leaves (Table 6) and found that cashew leaves absorbed more ^{14}C-urea than ^{32}P. Rao (1992) reported that aqueous sprays which are polar in nature are repelled by plant surfaces and so less absorption. But non polar sprays which have low viscosity and surface tension have stronger affinity for fatty substances and they wet the plants rapidly and so the absorption is more. Urea molecules are neutral and the phosphorus ions are anionic in nature. This difference in the chemical properties might be responsible for the differential absorption of these nutrients through foliage.

Phosphorus-32 applied on the lower surface was translocated more to other parts compared to the same applied on the upper surface. About 4 per cent of the absorbed phosphorus was translocated from the treated leaf when applied on the lower surface, but only 1.3 per cent was translocated when the application was done on the upper surface. The distribution pattern of ^{32}P (in cashew seedling) applied on the upper surface and lower surface is given in Fig. 8 and 9. Of the 1.3 per cent of the nutrient translocated from the treated leaf when applied on the upper surface, about 0.23 per cent reached the root, 0.72 per cent in the stem and 0.13 per cent in the two terminal leaves. On the other hand, out of 4 per cent of the nutrient translocated from the treated leaf (application on the lower surface), 1.1 per cent reached the root, about 1 per cent in the stem and 1.58 per cent in the two terminal leaves. The results indicate that translocation of ^{32}P was more towards the younger leaves and to the roots. Earlier works in maize (Biddulph *et al.*, 1958, and Datta and

Vyas, 1967) and soyabean (Ahlgren and Sudia, 1967) also showed that the translocation of foliar applied nutrients is more towards the young developing leaves and roots.

From the results, it is evident that the absorption and translocation of the foliar applied nutrients namely ^{14}C-urea and ^{32}P are greatly influenced by leaf age as well as leaf surface and they play a vital role in deciding the extent of absorption of foliar applied urea and phosphorus in cashew. It is also clear that for getting better results from foliar nutrition in cashew, care should be taken to direct the foliar sprays to the younger leaves, concentrating to the lower surface of the leaf.

b. Foliar absorption of ^{14}C-urea and ^{32}P in relation to duration of absorption and leaf surface

The amount of absorption of ^{14}C-urea increased with time upto a duration of 120 hours and the absorption did not increase by increasing the duration beyond 120 hours (Table 7). About 83.4 per cent of applied urea was absorbed within this period (120 h). The per cent absorption increased with increase in duration upto a period of 7 days. Within this period 90.71 per cent of the applied urea was absorbed. The amount, percentage and rate of absorption were more through the lower surface

The percentage absorption did not increase further by increasing the absorption time beyond six days. From the results it is clear that the absorption efficiency of foliar applied ^{32}P is low compared to urea and it may not be possible to increase the percentage absorption by allowing more time of absorption. For getting better efficiency of foliar applied nutrients, a minimum absorption time of seven days for ^{14}C-urea and six days for ^{32}P would be essential in cashew.

c. Diurnal variation in the foliar absorption of ^{14}C-urea and ^{32}P

The absorption of foliar applied ^{14}C-urea varied with the time of application in a day and the highest absorption was noticed when application was done between 11 00 and 14 00 hours (Table 9 and Fig. 18). The highest absorption (52.68 percent) was noticed when application was done at 13 00 hours. In the case of ^{32}P, the highest percentage absorption (27.92 percent) was noticed when the application was done at 11 00 hours. The foliar absorption was comparatively low when applied in the forenoon from 07 00 hours to 11 00 hours and in the afternoon from 14 00 hours to 18 00 hours. The results clearly indicate that time of application in a day is vital in deciding the extent of absorption of foliar applied nutrients.

The temperature and the duration of bright sunshine hours on hourly basis and the relative humidity recorded at 08.30 hours and 14.30 hours of the experimental day (nineteenth February, 1994) are given in Appendix 9. It can be seen that the hours of peak absorption coincided with hours of high temperature.

Enhanced absorption with increase in temperature and light intensity was reported in apple (Westwood and Batjer, 1958 and Shim et al., 1972) beans and cucumber (Gustafson, 1956 and Jyung and Wittwer, 1964), corn (Rains, 1968) and cherry (Flore and Bukovac, 1982).

The results indicate that time of application decides the efficiency of foliar applied nutrients to a greater extent. The ideal time for foliar application of urea would be between 11 00 hours and 14 00 hours and for phosphorus the best time would be around 11 00 hours.

d. Effect of teepol on foliar absorption of ^{14}C-urea and ^{32}P

Inclusion of a surfactant (0.05 per cent of teepol) enhanced the amount and per cent of absorption of ^{14}C-urea (Table 10 and Fig. 19, 20). Increase in the concentration of the surfactant beyond 0.05 per cent did not enhance foliar absorption. The percentage absorption of ^{14}C-urea has increased from 43.77 per cent (control) to

88.69 per cent due to the inclusion of 0.05 per cent teepol in the foliar spray. Similar effects of surfactants on foliar absorption had been reported by Cook and Boynton (1952), Westwood and Batjer (1958) and Edgerton and Haeseler (1959) in apple, Dybing and Currier (1961) in zebrina, apricot and pear and Coble et al. (1970) in honey vine milk weed.

Works done by cook and Boynton (1952) showed that surfactants such as Tween-80 (0.1 per cent) and Tween-20 (0.01 per cent) doubled the rate of absorption of urea by apple leaves. The results of the present study clearly indicate that inclusion of a surfactant namely teepol (0.05 per cent) is of great advantage in enhancing the efficiency of foliar applied urea in cashew.

Contrary to the effect of teepol observed on the foliar absorption of ^{14}C-urea, the absorption of foliar applied ^{32}P was drastically decreased due to inclusion of teepol (0.05 per cent) in the spray solution (Table 10). Swanson and Whitney (1953) also observed similar decreased absorption of ^{32}P due to inclusion of surfactant namely Tween-20 and Tween-80 in bean plants. The results clearly show that addition of teepol in foliar sprays involving phosphorus can exert a negative influence on foliar absorption and it will decrease the efficiency of foliar applied phosphorus.

e. Monthly variation on foliar absorption of ^{14}C-urea and ^{32}P

The main objective of the study was to find out the influence of month of application, leaf age and leaf surface on foliar absorption of ^{14}C-urea and ^{32}P by cashew trees under field conditions. Though the studies were conducted on monthly basis right from the flushing phase (November) to the harvesting phase, due to the intervention of rain, data relating November, December and January for ^{14}C-urea and November and January for ^{32}P could not be gathered.

The initial amount of ^{14}C-urea and ^{32}P (radioactivity dose) applied on the leaf surface was different during different months. Hence a comparative analysis could not be made to bring out the difference in absorption due to months, based on the data on the amount of radioactivity absorbed during different months. Therefore, to bring out the monthly difference in absorption, data on percentage absorption recorded during different months were subjected to pool analysis and presented.

The amount and percentage absorption of ^{14}C-urea did not differ due to the three leaf ages considered for the study (Table 11,12). The age of the leaves of the latest flush was ranging from one to six weeks and this age difference might have been insufficient to alter the physiological and anatomical character of the leaves to influence the foliar absorption. The larger absorption of nutrients through the lower surface of leaf was again confirmed in this experiment also (Table 11).

The percentage absorption of ^{14}C-urea was high during March compared to February (Table 12). The data on temperature, relative humidity (RH) and sunshine hours (Appendix 14) show that the atmospheric temperature and sunshine hours are high during March compared to February. Enhanced absorption due to increase in temperature and sunshine hours have already been discussed earlier under the heading diurnal variation in foliar absorption. Reddy (1993) reported that utilization of applied urea was more when foliar spray was done in the month of March coinciding with the flowering and fruiting period.

The differential absorption of ^{14}C-urea due to leaf age and month of application was also evident (Table 12) and the absorption was highest with the terminal leaves during March. From the results, it is clear that for getting greater efficiency of foliar applied ^{14}C-urea, the best month of application is March and it is advisable to direct the sprays to the terminal leaves of the latest flush.

Absorption of foliar applied ^{32}P differed with leaf age (Table 13). The absorption was higher with the mature leaves of the latest flush compared to the younger ones. This was contrary to the results observed with the absorption of ^{14}C-urea in relation to leaf age.

Greater absorption of ^{32}P through the lower surface is confirmed in this experiment also. Among the three months tried in this experiment (December, February and March), the absorption of ^{32}P was more during December and March (Table 12) and low during February. The differential absorption of ^{32}P due to leaf age and month of application was also evident from the study and the absorption was highest with the basal leaves during December.

It is apparent from the weather data during the experimental period (Appendix 14) that the foliar absorption of ^{32}P was RH dependent than temperature dependent. The month during which the ^{32}P absorption was the highest (December), the RH was high. The temperature and sunshine hours were low during this month. The results suggest that foliar absorption of ^{32}P can be more during periods of high RH (67 per cent), low day temperature (27.3°C) and low sunshine hours (6.4 h). Greater absorption of foliar applied urea (Volk and Mc Auliff, 1954), maleic hydrazide (Zukel et al., 1956) and 2, 4-D (Pallas, 1958) under high humidity had been reported earlier. From the results it is apparent that the months with high temperature, low RH and more sunshine hours are conducive for the greater absorption of foliar applied urea and months with low temperature, high RH and less sunshine hours are favourable for better absorption of foliar applied phosphorus.

An effort was also made to confirm whether the nutrients (^{14}C-urea and ^{32}P) applied on a particular leaf in the tree has been absorbed and translocated to the neighbouring leaves. Sample from neighbouring leaves were subjected to radioassay and confirmed that the foliar applied ^{14}C-urea is very well absorbed and translocated to the neighbouring leaves.

From the limited data available from the study, it appears that the best time for foliar application of urea is March and that of phosphorus is December.

Part III. Root absorption of ^{14}C-urea and ^{32}P

Root absorption of ^{14}C-urea and ^{32}P from solution culture differed with duration of absorption attaining its peak within the first eight hours and it did not increase further with time (Table 14 and Fig. 21, 23). The percentage absorption of ^{14}C-urea and ^{32}P also showed a similar trend (Fig. 22). The rate of absorption was the highest initially (within four hours) and the rate declined with increase in the duration of absorption (Fig. 21, 23). Several workers reported increased absorption with time in beans (Biddulph, 1940), maize (Handley and Overstreet, 1961), wheat (Picciurro et al., 1967) and barley (Kramer, 1978). Picciurro et al. (1967) showed that initial rate of NH_4^+ absorption by excised roots of wheat was rapid and the rate decreased with time. In a study on the radioactive strontium uptake by excised barley roots, Kramer (1970) reported that the relationship between time and ion uptake was curvilinear, showing rapid uptake for a short time followed by a long period of slower uptake. Molecular absorption of urea by cashew roots and leaves was reported by Salam and Kamalam (1993). Between the nutrient species (^{14}C-urea and ^{32}P) roots absorbed more ^{14}C-urea compared to ^{32}P (Table 15).

An attempt was also made to compare the root absorption with foliar absorption. Between the two absorbing organs namely root and leaf, root absorption (from solution) was considerably more compared to foliar absorption both for ^{14}C-urea and ^{32}P (Table 15). The difference between root absorption and foliar absorption was larger during short periods of absorption(upto 12 hours) and this difference was narrowed down with increase in absorption time in the case of urea (Fig. 24). But for ^{32}P, root absorption continued to be more than foliar absorption, irrespective of duration of absorption (Fig.25).

From the results it is evident that urea can be absorbed by cashew roots in the molecular form itself. Similarly, cashew roots absorb ^{32}P also from solution culture. The absorption was more for urea than ^{32}P and in both the cases, the maximum absorption takes place within a period of eight hours.

Part IV. Cuticle thickness and stomatal index.

The cuticle thickness was measured in relation to leaf age (One week to 18 week old leaves). The older leaves had thicker cuticle and the younger ones had thinner cuticle (Table 16 Plate 2).

The cuticle on the upper surface (5.25 μ) is thicker and that on the lower surface (3.87 μ) is thinner (Plate 3). The lower surface of the youngest leaf had the thinnest cuticle (2.79 μ).

Cuticle is one of the most important physical barrier that limits penetration of foliar applied nutrients into the leaf (Darlington and Circulis, 1963., Denna, 1970 and Martin and Juniper, 1970 and Leece, 1978). The cuticle on the lower surface of leaves of tobacco, bean and tomato were thinner than that on the upper surface (Jyung *et al*., 1965) and the epicuticular wax which is present on the outer surface of cuticle increased with leaf development (Bukovac *et al*., 1979). Naturally the leaves with thinner cuticle may allow easy entry of nutrients into the leaf tissue.

Stomatal index is another important anatomical character that decides foliar absorption of nutrients. In cashew, the upper surface is completely devoid of stomata and the stomata are present only on the lower surface (Table 17 and Plate 4). Kallarackal and Somen (1992) reported similar results in cashew. The stomatal index was more with the youngest leaves compared to older leaves (Plate 5). Franich *et al*. (1977) observed that the number of stomata decreased with increase in the age of trees is *Pinus radiata*. Guard cells of the stomata play a special role in foliar absorption and these cells are equipped with more ectodesmata (Nagarajah, 1978). It is a well established fact that leaf surface with thinner cuticle and a higher stomatal index will allow easy entry of foliar applied nutrients into the tissues. In the present study it was found that lower surface of the youngest leaves has thinner cuticle and higher stomatal index. These results explain our earlier observation (Part II) that lower surface of youngest leaves are more efficient in absorbing foliar applied nutrients.

Summary

SUMMARY

An investigation was undertaken at the College of Horticulture, Vellanikkara during 1993-'94 to study the foliar absorption of nitrogen and phosphorus by cashew. The main objectives of the study were to develop a method to quantify the foliar absorption of ^{14}C-urea and ^{32}P, to identify the factors affecting foliar absorption, to compare the root absorption with foliar absorption and to study the leaf anatomy of cashew in relation to foliar absorption.

The salient results of the investigation are summarised below.

A method was developed to study the foliar absorption of ^{14}C-urea and ^{32}P. Accordingly, a sequential washing programme involving four washings each with 50 ml of 2 per cent teepol was found to be reasonable for quantifying the adsorbed ^{14}C-urea and ^{32}P on cashew leaves.

Absorption and translocation of the foliar applied nutrients namely ^{14}C-urea and ^{32}P were influenced by leaf age as well as leaf surface. The absorption and translocation were the highest when applied through the lower surface of younger leaves.

A minimum absorption time of seven days for ^{14}C-urea and six days for ^{32}P is essential for getting greater absorption of foliar applied nutrients in cashew. About 83.4 per cent of foliar applied urea was absorbed within 144 hours. The absorption efficiency of phosphorus is low and only 38.86 per cent was absorbed within the same absorption period and it did not increase by increasing the time of absorption.

The absorption of foliar applied ^{14}C-urea and ^{32}P varied with time of application in a day. The absorption of urea was the highest when application was done between 11 00 hours and 14 00 hours and that of phosphorus was the highest when applied at 11 00 hours.

Inclusion of a surfactant namely teepol (0.05 per cent) enhanced the efficiency of absorption of foliar applied urea and decreased the absorption of foliar applied phosphorus.

The percentage absorption of urea was higher during March compared to February. Absorption of urea was highest with the terminal leaves of latest flush. Among the three months (December, February and March) the absorption of ^{32}P was more during December and March and low during February. The absorption of ^{32}P differed with leaf age and it was highest with the basal leaves of the latest flush.

Cashew roots absorbed urea and phosphorus from solution culture. The absorption of urea was in molecular form. The root absorption of urea was also more than phosphorus. The highest root absorption of ^{14}C-urea and ^{32}P from solution culture occur within a period of eight hours and it did not increase further with time.

The cuticle thickness of cashew leaves differ with leaf age and leaf surface; the older leaves has thicker cuticle and the younger leaves has thinner cuticle. The upper surface of the leaf has thicker cuticle and the lower surface has thinner cuticle.

In cashew, the upper surface is completely devoid of stomata and the stomata are present only on the lower surface. The stomatal index is more in younger leaves.

A six year old cashew tree (var. Anakkayam-I) at the time of flushing (during November) has a total leaf area of 54.15 m^2 on its crown, of which 80 per cent accounts for the latest flush.

Future line of work

In the present study, the investigation on the monthly variation in the foliar absorption of nitrogen and phosphorus could not be carried out covering all the months of the year. Hence it is felt that a detailed study covering all the months is essential to bring out the seasonal influence on foliar absorption.

Also, the study of the influence of surfactants on foliar absorption was confined only to teepol. It would be worth-while to study the influence of a variety of cheaply availablle surfactants to enhance foliar absorption.

It would also be interesting to study the extent of foliar absorption of nitrogen and phosphorus in combination with commonly used insecticides.

A study to bring out the extent of absorption of foliar applied nutrients in relation to the different concentration of nutrient solution would also be of immense value.

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* Originals not seen

Appendices

Appendix 1. Abstract of Anova

Foliar absorption of ^{32}P in relation to leaf position and leaf surface

Source	d.f	Mean square
Position (A)	1	0.127**
Surface (B)	1	0.106*
AB	1	0.001
Error	8	0.007

Appendix 2. Abstract of Anova

Radioactivity (cpm) in the washings from cashew leaves applied with ^{14}C-urea and ^{32}P in relation to the number of washings

Source	d.f.	Mean square	
		^{14}C-urea	^{32}P
Treatment	7	1905.79**	0.83**
Error	16	128.52	0.021

Appendix 3. Abstract of Anova

Foliar absorption of ^{14}C-urea by cashew seedling in relation to leaf position and leaf surface

Source	d.f	Mean square	
		Amount absorbed	Per cent absorption
Position (A)	1	0.002	17.829
Surface (B)	1	0.085**	968.92**
AB	1	0.000	2.426
Error	8	0.004	29.858

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

Appendix 4. Abstract of Anova

Foliar absorption of ^{32}P by cashew seedlings in relation to leaf position and leaf surface

Source	d.f	Mean square: Amount absorbed	Per cent absorption	Content in the treated leaf after washing	Amount translocated from the treated leaf
Position (A)	1	0.036*	50.1*	0.039*	0.047
Surface (B)	1	0.178**	320.3**	0.165**	1.558**
AB	1	0.033*	42.86*	0.035*	0.032
Error	8	0.004	5.723	0.004	0.058

Appendix 5. Abstract of Anova

Foliar absorption of ^{14}C-urea and ^{32}P in relation to leaf age.

Source	d.f.	Mean square: ^{14}C-urea		^{32}P	
		Amount absorbed	Per cent absorption	Amount absorbed	Per cent absorption
Treatment	10	0.01**	120.99**	0.025*	96.371**
Error	22	0.002	21.82	0.008	26.621

Appendix 6 Abstract of Anova

Foliar absorption of ^{14}C-urea in relation to duration of absorption and leaf surface

Source	d.f	Mean square: Amount absorbed	Per cent absorption	Rate of absorption
Duration (A)	1	1.063**	6516.043**	1.229**
Surface (B)	9	0.45**	804.97**	0.657**
AB	9	0.033**	30.45**	0.053**
Error	40	0.003	6.316	0.008

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

Appendix 7. Abstract of Anova

Foliar absorption of ^{32}P in relation to duration of absorption and leaf surface

Source	d.f	Mean square: Amount absorbed	Mean square: Per cent absorption	Mean square: Rate of absorption
Duration (A)	1	0.219**	468.61**	0.219**
Surface (B)	9	0.059**	111.47**	1.353**
AB	9	0.004	15.829**	0.004**
Error	40	0.003	5.710	0.003**

Appendix 8. Abstract of Anova

Diurnal variation in the foliar absorption of ^{14}C-urea and ^{32}P

Source	d.f.	Mean Square: ^{14}C-urea Amount absorbed	Mean Square: ^{14}C-urea Per cent absorption	Mean Square: ^{32}P Amount absorbed	Mean Square: ^{32}P Per cent absorption
Treatment	10	0.027*	210.725*	0.057**	67.928**
Error	22	0.01	71.763	0.012	10.038

** Significant at 1% level

* Significant at 5% level

Appendix 9

Temperature, relative humidity (RH) and sunshine hours on hourly basis during the experimental day (19-02-92)

Time	Temperature (°C)	R.H. (%)	Sunshine hours (h)
7-8 hours	27.0	-	0.9
8-9 ,,	32.0	74	1.0
0-10 ,,	34.0	-	1.0
10-11 ,,	34.5	-	1.0
11-12 ,,	36.9	-	1.0
12-13 ,,	38.7	-	1.0
13-14 ,,	39.6	-	1.0
14-15 ,,	40.1	57	1.0
15-16 ,,	38.5	-	1.0
16-17 ,,	35.5	-	1.0
17-18 ,,	34.0	-	0.75

Appendix 10 Abstract of Anova

Effect of teepol on foliar absorption of ^{14}C-urea and ^{32}P

Source	d.f.	Mean Square: ^{14}C-urea		Mean Square: ^{32}P	
		Amount absorbed	Per cent absorption	Amount absorbed	Per cent absorption
Treatment	2	0.095**	710.45**	0.110**	164.76**
Error	6	0.0086	25.54	0.004	8.106

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

Appendix 11 Abstract of Anova

Foliar absorption of ^{14}C-urea in relation to age of flush and leaf surface during different months

Source	d.f.	Amount absorbed	
		February	March
Age (A)	2	0.003*	0.001*
Surface (B)	1	0.028**	0.009**
AB	2	0.002*	0.0005
Error	12	0.002	0.001

Appendix 12. Abstract of Anova

Foliar absorption of ^{32}P in relaiton to age of flush and leaf surface during different months

Source	d.f.	Mean Square		
		December	February	March
Age (A)	2	0.005	0.009*	0.007**
Surface(B)	1	0.002*	0.019*	0.033**
AB	2	0.002	0.0005	0.0005
Error	12	0.003	0.002	0.0004

** Significant at 1% per cent levell

* Significant at 5% per cent level

Appendix 13 Abstract of Anova

Variation in the per cent absorption of ^{14}C-urea and ^{32}P due to different month of application, age of flush and leaf surface

	Mean Square			
Source	d.f.	^{14}C-urea	d.f.	^{32}P
Month :(A)	1	574.881**	2	4695.611**
Age ..(B)	1	873.202**	1	1338.624**
AB	1	2.539	2	58.291
Surface :(C)	2	14.618	2	170.83**
AC	2	124.376**	4	54.53*
BC	2	58.027	2	8.447
ABC	2	24.777	4	8.28
Error	24	19.219	36	18.673

Appendix 14

Mean day temperature, relative humidity (RH) and bright sunshine hours during experimental period (5days) during different months.

Months	Temperature(°C)	RH(%)	Sunshine hours(h)
December (17-12-93 to 22-12-93)	27.3	67	6.4
February (02-02-94 to 07-02-94)	28.6	54	10.09
March (05-03-94 to 10-03-94)	30.0	45	10.1

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

Appendix 15. Abstract of Anova

Absorption of ^{14}C-urea and ^{32}P through roots of three months old cashew seedlings in relation to duration of absorption.

Source	d.f.	^{14}C-urea			^{32}P		
		Amount absorbed	Per cent absorption	Rate of absorption	Amount absorbed	Per cent absorption	Rate of absorption
Treatement	4	0.032**	526.566**	0.507	0.018**	93.563	0.556**
Error	15	0.002	20.568	0.002	0.002	9.263	0.002

Appendix 16. Abstract of Anova

Cuticle thickness of cashew in relation to leaf age and leaf surface

Source	d.f.	Mean square
Age (A)	2	106.463**
Surface (B)	1	86.251**
AB	2	3.494**
Error	174	0.537

Appendix 17. Abstract of Anova

Stomatal index of cashew leaf in relation to leaf age and leaf surface.

Source	d.f.	Mean square
Treatment	2	119964.2**
Error	57	5460.2

**Significant at 1% level

ABSTRACT

An investigation was undertaken at the College of Horticulture, Kerala Agricultural University, Vellanikkara during 1993-'94 to study the foliar absorption of nitrogen and phosphorus by cashew. The main objectives of the study were to develop a method to study the foilar absorption of ^{14}C-urea and ^{32}P and to identify the factors affecting foliar absorption of nitrogen and phosphorus by cashew. It was also aimed to compare the root absorption with foliar absorption and to study the leaf anatomy of cashew in relation to foliar absorption. The experiment was done using three month old cashew seedlings and six year old cashew trees (var.Anakkayam-1). The salient findings are abstracted below.

A leaf washing technique was developed to quantify the foliar absorption of ^{14}C-urea and ^{32}P. Accordingly a sequential washing programme involving four washings each with 50 ml of 2 per cent teepol was found to be reasonable to quantify the foliar absorption of ^{14}C-urea and ^{32}P in cashew.

Factors affecting foliar absorption of urea and phosphorus by cashew have been identified. Leaf age, leaf surface, duration allowed for absorption, time of application in a day, month of application in an year and presence of a surfactant in the spray solution are certain

important factors that are found to decide the extent of absorption of foliar applied ^{14}C-urea and ^{32}P in cashew.

Greater absorption of foliar applied urea was obtained when nutrient solution was sprayed in 0.05 per cent teepol between 11 00 hours and 14 00 hours, directing the spray to the lower surface of terminal leaves of latest flush during March and by giving a minimum absorption period of seven days.

The efficiency of foliar applied phosphorus was increased by spraying around 11 00 hours to the lower surface of basal leaves of latest flush during December and by giving a minimum absorption period of six days.

Root absorption from solution culture was more compared to foliar absorption in the case of ^{14}C-urea and ^{32}P. The absorption efficiency of ^{32}P both through root and leaf was low compared to ^{14}C-urea.

The cashew leaves contain thicker cuticle on the upper surface with no stomata and thinner cuticle on the lower surface with large number of stomata. The latest flushes of a six year old cashew tree (var. Anakkayam-1) during flushing account for 80 per cent of total leaf area in the crown.