EFFECT OF DIFFERENT SHADINGS ON THE ENVIRONMENTAL PARAMETERS

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

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DECLARATION

I hereby declare that this thesis entitled **"EFFECT OF DIFFERENT SHADINGS ON THE ENVIRONMENTAL PARAMETERS"** is a bonafide record of research work done 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, associateship, fellowship or other similar title, of any other University or Society.

Tavanur
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CERTIFICATE

Certified that this thesis entitled **"EFFECT OF DIFFERENT SHADINGS ON THE ENVIRONMENTAL PARAMETERS"** is a record of research work done independently by **Mrs. Bindu .P.K.**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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SYMBOLS AND ABBREVIATIONS

Ag.	-	Agriculture
Agric.	-	Agricultural
Agron.	-	Agronomy
a.m.	-	ante meridian
ASAE	-	American Society of Agricultural Engineerins
Aust.	-	Australian
Bull.	-	Bulletin
B50	-	black shade net with 50% shade
B75	-	black shade net with 75% shade
$Cal/cm^2/day$	-	Calories per square centimeter per day
Can.	-	Canadian
cm	-	centimetre (s)
CIAE	-	Central Institute of Agricultural Engineering
CO2	-	Carbon dioxide
E	-	East
et al.	-	And others
Engg.	-	Engineering
fc	-	foot candle
Fig.	-	Figure
g	-	gram (s)
G50	-	green shade net with 50% shade
G75	-	green shade net with 75% shade
GI	-	Galvanized Iron
h	-	hour (s)
ha	-	hectare(s)
HDPE	-	high density polyethylene
Hort.	-	Horticulture
IARI	-	Indian Agricultural Research Institute
IIT	-	Indian Institute of Technology
i.e.	-	That is
Int.	-	International
IR	-	Infrared

J.	-	Journal
Kg	-	kilogram (s)
Kg/cm2	-	Kilogram per square centimeter
KCAET	-	Kelappaji College of Agricultural Engineering and Technology
m	-	metre (s)
mm	-	millimetre (s)
m^2	-	square metre (s)
mha	-	Million hectare
Mgt.	-	Management
N	-	North
Neth.	-	Netherland
NRCS	-	National Research Centre for Spices
No.	-	Number
PAR	-	Photosynthetically active radiation
p.m.	-	Post meridian
PE	-	polyethylene
Proc.	-	Proceedings
pp.	-	Pages
Rs.	-	Rupees
Res.	-	Research
RH	-	Relative Humidity
Sci.	-	Science
Sl. No.	-	Serial Number
Soc.	-	Society
Symp.	-	Symposium
Trans.	-	Transactions
Trop.	-	Tropical
UV	-	ultraviolet
V	-	Volt (s)
W/m2	-	Watt per square metre
W/m	-	Watt per metre
	-	Minute (s)

:	-	is to
°	-	degree (s)
°C	-	Degree centigrade
/	-	Per
$	-	Dollars
%	-	per cent
&	-	And

Introduction

INTRODUCTION

Agriculture has been a mainstay of human beings from time immemorial. This branch of applied science has derived its name from the Latin word 'ager' meaning land or field and the 'cultra' meaning cultivation. Thus agriculture refers broadly to the technology of raising plants and animals.

India is one of the most populated countries in the world; which has 15 per cent of the global population covering 2.5 per cent of the geographical area. India's population has crossed 1,000 million mark by the end of the century. The problem is further accentuated because the economy continues to be largely agrarian with 70 per cent of the economically active population depending on agriculture as against less than 10 per cent in the Western countries and about 17 per cent in Japan. Therefore we need well co-ordinated and concerted efforts on many fronts including agricultural development of less developed and less endowed regions, diversification of agricultural production systems and search for appropriate technologies.

Agriculture has the responsibility of meeting the basic food, feed and fibre requirements of society. As the society enlarges and becomes more sophisticated, the requirement also increases and becomes more varied. Apart from feeding the growing population, the concept of exporting high value farm goods and using the foreign exchange earned for relatively cheaper items, if need be, has been gaining legitimacy of late. Agriculture based exports are necessary to sustain the tempo of development of farm sector as a whole. It plays a significant role in employment generation and diversification of agriculture. Export of new items is picking up at a much faster pace than that of traditional items. Fresh and processed fruits and vegetables, flowers and other floriculture products have a vast export potential. Therefore, agricultural practices in a society must keep on improving if the society has to continue its upward growth.

Agriculture in India has made excellent progress after independence. Initiatives taken have changed the agriculture scene and has transformed it from traditional to technology oriented, from extensive to intensive, from subsistence to surplus, from monocrop to multicrop and from open cultivation to controlled cultivation and has ushered in an era of green, white, blue, yellow and brown revolutions in the country. As a result, food grain productivity in India has increased tremendously during the last years. The scenario has not been that rosy in the case of other crops such as vegetables, fruits, etc. While all efforts must be made to harness the maximum potential of the available options, new ways of increasing the productivity should also be pursued so that the society's expectations are fulfilled.

Proper land use planning is basic to productive agriculture. There will be only marginal increase in the net sown area although the area under forests can be increased to some extent by reclaiming the uncultivated areas. To boost agricultural production at the rate needed to meet the demands, it is necessary to adopt new technologies with the aim of improving productivity per unit area.

Our knowledge about plant physiology suggests that for a plant of given genetic make-up, the factors that affect the plant growth are (1) light, (2) temperature, (3) air composition and (4) nature of root medium. There is practically no way to substantially modify or control light, temperature and air composition parameters in open field cultivation. Therefore, crop production in open fields still remains to be contingent upon good weather conditions. With the increasing competition for resources and unpredictable climate changes, the traditional open field cultivation needs to be re-assessed.

Agricultural production is hampered with unfavourable environment as well as excessive rain and drought. To make optimum use of our land, air and water resources, agriculture has to be in tune with the prevailing environmental conditions by way of selection of more suitable crops and varieties, agronomic, cultural and engineering practices. Whenever and wherever necessary, efforts have been made to modify the environment by way of irrigation, drainage, fertilizer application, etc.

To tap the full potential of a crop, the crop environment needs to be suitably regulated. Therefore to increase the agricultural productivity the controlled environment agricultural practices can play a major role. In controlled environment agriculture, the factors like light, temperature and air composition which affect the plant growth can be modified.

Controlled environment agriculture in the form of green houses, low tunnels, shading houses and cloches are being practiced at commercial levels in many countries. This technology gives high productivity and permits production of crops under unfavourable land and climatic conditions, where traditional cultivation would not be possible. About 75 M ha of area which is unsuitable for cultivation can be made productive by bringing them under controlled environment agriculture.

Cloches and tunnels cover an individual plant or a row of plants. They have usefulness under cold climates, where the advantage of greenhouse effect is realised for keeping young plants and seedlings warm. These structures also protect the plants from high winds, intensive rains, hail and snow.

Mulches is the simplest of all covered cultivation methods where the soil surface around plants is covered with materials such as crop residues, leaves, manure, paper, plastic films, petroleum products, gravel etc. Surface mulch affects both diurnal and seasonal fluctuations in soil temperature.

Green houses are framed or inflated structures covered with transparent or translucent material in which crops may be grown under the conditions of at least partially controlled environment and which are large enough to allow a person to walk within them to carry out agricultural operations. This technology is highly productive, conservative of water and land and protective of the environment.

But the high initial investment is a major hurdle for adopting greenhouse cultivation.

Greenhouse cultivation is widely accepted in developed countries where the climate is extreme. In India with its moderate climate and developing economy, we should think about cheaper methods of controlled environment agriculture.

Shading is a cheaper method of environment control, though the degree of control is less. From ancient times itself we used to propagate seeds under shade and also the newly transplanted seedlings were given shade. The locally available materials like leaves were commonly used for this purpose.

The shading requirement in the large scale cultivation of plants like vegetables, flowering plants etc. especially during summer, led to the manufacture of shade nets which is known as 'agro shade nets'. Shade nets of different shading percentages and colours are commercially available. The shade nets are useful in the vegetative propagation of seeds and plants and it also protects valuable plants against excess sunlight, heat, cold, wind, frost, etc.

The light requirement of various plants for the maximum vegetative growth and yield varies. The shade response of almost all the crops have been studied and are classified as shade intolerant, shade tolerant and shade loving plants. For the selection of appropriate shade nets for these crops, we should be aware of the variation of environmental parameters under different shading conditions. Such studies have not yet conducted in the case of agro shade nets.

The agro shade nets are made of high density polyethylene (HDPE) plastic which is treated with best known UV stabilizers in the highest possible concentration that are upto the latest technical knowledge. Analyzing the shading effects of these nets, crops can be grown under optimum light intensity, temperature and humidity which vary from crop to crop.

Under this context an investigation was undertaken with the following specific objectives.

1. To study the variation in the light intensity under different shading conditions.

2. To study the variation in the intensity of solar radiation under different shading conditions.

3. To study the variation in temperature and humidity under different shading conditions.

4. To study the crop response to the different intensities of light, temperature and humidity under different shading conditions.

Review of Literature

REVIEW OF LITERATURE

Shading is an artificial method of plant environmental control. It regulates the light intensity to a great extent and temperature and relative humidity to some extent. The plant growth and yield are dependant on these factors. Some plants are shade loving, while some others are shade intolerant. Also plant response varies under different light intensities. While shading plants care should be taken to provide proper level of shades which are conducive to their growth and yield should be maximum.

Research work on the variation of the environmental parameters under shade is relatively scanty. The literature available on the monitoring of the environmental parameters in other forms of protected cultivation and the studies conducted on the shade response of some important plants are, hence, reviewed in this chapter. The shade levels tried in each of these experiments apparently had been highly variable and these had not been mentioned in many of the reports. Whenever the shade levels are mentioned, these are included in the review. Where these are not available, the overall effects of shaded are only presented.

2.1 Protected Cultivation

To make sure that the world's future billions have enough to eat, we must direct our knowledge and skills to developing ways of conserving our air, land and water while researching new technologies for increasing food production. In places where the population density is rather high and cultivated land is limited, the way to improve production is to adopt protected cultivation. Under protected cultivation, modification of the climate to create an environment for maximum production is possible.

Nakashima *et al.* (1970) carried out studies to clarify the effects of various plastic materials on the yield of vegetables.

Van den Muijzenberg (1980) documented the protected cultivation of crops, starting as far back as the Babylonians and the ancient Chinese.

El-Aidy (1984) from his research on the use of plastics in the production of some vegetable crops in Egypt concluded that low tunnels give maximum yield compared to open, perforated plastic covers and black mulch.

El-Aidy (1992) reported that use of controlled environmental agriculture in the commercial production of vegetables has increased steadily since they were introduced in the 1970's and vegetable production has increased accordingly.

2.1.1 Shading

It is a simple form of protected cultivation in which crops are grown under temporary or permanent shading structures. The size and shape of the structures varies. Shade nets and PE sheets are commonly used for shading. This will vary climate to some extent.

Robledo (1984) reported that the use of plastic house in agriculture is achieving wide popularity due to the factor that farmers obtain more benefits from this cultivation method than from the traditional open-air system, as production increases.

Dfez *et al.* (1986) compared the cultivation under plastic-house and in the open air during winter and summer seasons. An attempt was made to compare production factors (i.e., fruit weight, number of fruits per plant and per cluster) as well as quality factors. Under plastic-house conditions, production was 50 per cent more than in the open air. Fruit weight did not vary significantly. Therefore, production increase was due to the greater number fruits per plant and of fruits per cluster under plastic house (7.4) than in the open-air (4.7).

Jimenez (1991) reported that the shelter nets were used for the production of tomatoes in the Canary Islands. They consist of a rigid frame and translucent net covering. The advantages of this type of structures include low cost, wind resistance, easier climatic control, savings in irrigation water and improved pollination. The disadvantages include slower crop development than in greenhouses, reduced light transmission, pest control is more difficult and carbon dioxide cannot be used.

Willits (1991) conducted experiments with different shading materials. Black plastic, white painted plastic and white fabrics of different weaves were tested. Results were compared with a computer model of the test facility and they showed that black plastic materials were inefficient shades since they absorb large amount of solar energy which is not easily reflected. The best materials were the white fabrics.

2.1.1.1 Types of Shade Structures

Several types of shade structures are in common use. They vary from the traditional type to the modern quonset-type structures. Shading materials also vary widely.

Lalitha Bai (1981), Sansamma (1982) and Krishnankutty (1983) conducted the shade experiments in pandals with flat top. Unplated coconut leaves were laid over the top for obtaining different shading intensities.

Brazenor (1986) reported on the elaborate designs of shade structures for commercial industries.

Bucklin (1987) presented the existing methods for designing shade structures for greenhouses. Techniques used by Florida's plant protection industry were evaluated. He discussed the shade cloth, attachment of shade cloth to structure, cables, poles foundations and anchors, reduction of air velocity, control of light level, temperature reduction, cold protection, design loads, shade cloth stress distribution, construction, modes and causes of failure.

Smith *et al.* (1992) developed a low cost shading structure that offers durability and simplicity. The quonset-type structure uses the readily available materials, including polyvinyl chloride pipe, construction-grade reinforcing bars, nylon rope and commercial shade fabric. The total cost for a 3.0 x 6.0 x 2.4 m structure that provided 47 per cent shade was $ 88.00. The structure offers substantial flexibility in terms of size and degree of shading without significantly altering the design. The structure was durable under a wide range of weather conditions, and the design allowed sufficient air movement to prevent a stagnant air layer from developing over the crop.

2.1.1.2 Effect of Shading on Environmental Parameters

The environmental parameters such as temperature, relative humidity, intensity of solar radiation and intensity of photosynthetically active radiation vary under shading. For the efficient selection of shading material and shading intensity for each crop, the variation in the environmental parameters should be evaluated.

Franz (1983) studied the effect of environmental factors on crop growth and found that the formation of characteristics that are typical of the plant and yield or content of active principles depend on the actual environmental factors.

Hornok (1986) conducted experiments on the relations between the environmental factors and the production of a certain type of special metabolic products. The reaction of different species to the same factor was found to be different. Therefore, he concluded that any common interpretation of the effect of a given environmental factor (light, temperature, moisture, etc.) would be a practical mistake and more elaborated studies are necessary to investigate the effect of these factors for every separate species.

2.1.1.2.1 Temperature

Temperature is a dominant factor in the environment for the growth of plants. The rate of any physiological process occurring is markedly influenced by the temperature factor. The important role of temperature in growth might well be summarised in its effect on photosynthesis and respiration. The higher temperatures are detrimental to plant growth.

Went (1957) carried out studies on the effect of temperature on growth and fruit set. He found that at lower temperatures, the foliage or fruit ratio was different, the leaves were bigger and the fruit set improved which favoured the development of bigger fruits.

Watanabe (1959) noticed that high temperatures, natural day length and heavy irrigation increased vegetative growth, but did not affect flower bud development in tomato seedlings. At low light intensities a longer time was required for flower bud differentiation. The number of leaves to the first inflorescence was affected by low temperatures, but not by day length or irrigation. The number of flower buds and the degree of flower development were affected by light intensity, day length and irrigation. The maximum early and total yields were obtained from plants grown under natural day length conditions at 20-25°C.

Schaible (1962) observed the reduction of fruit set in summer due to high air temperature.

Hussey (1963) compared the growth of tomato seedlings at constant temperatures of 25°C and 15°C. The rates of leaf formation and leaf growth increased with temperature. Temperature had a greater effect on leaf growth than on leaf formation. More leaves were formed before flowering at 25°C than at 15°C.

Wang (1963) presented graphical methods for the analysis of rainfall and temperature data in relation to tomato yields. Both linear and non-linear correlations of various temperature and rainfall parameters with tomato yields were established. The methods presented will be usefull in the prediction of yields and in area appraisal for tomato production.

Abdalla and Vernerk (1968) studied the effect of high air temperature on flower shedding during summer and found that the high air temperature increased flower shedding.

Sakiyama (1968) noticed that during summer, due to high air temperature, tomato fruits produced were small and the yield was reduced. Also the direct sunlight caused sunburn.

Walker and Ho (1977) found a positive correlation between the assimilate import by fruits and the temperature and reported an enhancement of the specific growth rates of fruits by temperature.

Smith *et al.* (1984) made an analysis of the environment inside a plastic tunnel with a without 30 per cent shade cloth, and in shade houses with 15 and 40 per cent shade cloth. Air temperatures under shade inside plastic were not different to those under plastic alone due to the free air movement between these two environments inside one tunnel. Under shade houses, air temperatures were always lower depending on the amount of shading.

Oyabu *et al.* (1988) reported that for summer cropping, shading individual plants with tufnell covers and mulching the soil with white – black (polyethylene) film controlled the rise in soil temperature and resulted in higher yields.

Varghese Thomas (1989) recorded the maximum and minimum temperatures, relative humidity and light intensity at 15 points inside a lower cost green house. They indicated that the temperature and relative humidity do not change significantly.

Galan Sauco (1992) studied the physiological production differences between green house and open air bananas in Canary Islands. Temperature was the main factor governing banana growth and development. Green house bananas exhibited greater height.

2.1.1.2.2 Relative Humidity

For a crop which is well watered, air humidity may not have any effect. But, if water is in short supply, higher air humidity can help in reducing the rate of transpiration and hence the irrigation requirements.

Amsen (1981) from his experiments on environmental conditions in different types of greenhouses, found that the air humidity showed a pronounced difference between permanently insulated houses and those with single film. This was due to higher wall and roof temperatures in the insulated greenhouses.

Bakker *et al.* (1987) studied the effect of day and night humidity on growth and production of glasshouse vegetable crops in detail.

Grange *et al.* (1987) also reviewed the effect of humidity on the growth of horticultural crops.

Bakker (1988) investigated the effect of day and night humidity on growth and production of autumn and spring grown cucumbers, tomatoes and sweet peppers in a series of glasshouse experiments. The effect of humidity on the final yield differed clearly between the three investigated fruit crops. Yield of cucumber was increased by high humidity at day, but did not respond to humidity at night or 24 h average. The final yield of tomato, however, was reduced by high humidity at night or 24 h average, while humidity at day had no significant effect. Sweet pepper did not respond to humidity by day, night or 24 h average with respect to final yield. The effects of humidity on growth were comparable with those on final yield. Growth of cucumber was enhanced; growth of tomato was reduced, while the growth of sweet pepper was not affected by high humidity. It seems likely therefore, that part of the effect of humidity on final yield is the result of differences in leaf area. Although, the effects on final yield differed between the three crops, in all cases the fruit quality at harvest was reduced by high humidity. Consequently the production was of lower monitory value. The recommendation for optimum fruit production and quality of cucumber is to maintain high day time humidity but to avoid high 24 h average humidity. With tomato however, high day – time humidity and 24 h average humidity should be avoided. With sweet pepper a good quality can be obtained by avoiding high 24 h average humidity. Growth and development of the crop was regulated most by the 24 h average temperature, both day and night temperature had similar effects.

Hand (1988) carried out investigations to find the effects of atmospheric humidity on greenhouse crops. He reported that from a crop production stand point the test strategy is to maintain a high humidity during the day to avoid a too high humidity at night. Such a regimen will maximize quality of output and minimize the risk of plant diseases.

Pelletier (1988) during the trials with cucumber grown with or without misting to maintain relative humidity at 70 per cent, noticed an increase in yield.

Abou-Hadid and El-Beltagy (1990) conducted water balance studies under plastic house conditions in Egypt. They observed a more stabilized curve between 63 and 72 per cent in comparison with open field which range between 30 and 35 per cent.

2.1.1.2.3 Solar Radiation

In many of the crops, solar energy available is a crucial factor determining the final yield. In the energy balance, solar radiation absorbed by the various component surfaces constitutes the major heat term and therefore it should be calculated as accurately as possible.

Schoch (1972) studied the effect of shading under high solar radiation conditions and found that under such conditions, shading at an early stage of plant development increased cell division and volume in leaves and whole plant dry matter and also positively affected fruit growth and yield.

Challa (1976) considered 25°C to be the optimum growth temperature for cucumbers and showed that the CO_2 uptake of 5 leaf plants was still increasing at an irradiance of 200 W/m^2, the maximum level tested.

North *et al.* (1978) and Smith *et al.* (1979) from their studies indicated that the radiant flux density was 400 W/m^2 and 300 W/m^2 under plastic and plastic and 30 per cent shade respectively.

Glenn (1984) reported a high statistical correlation between lettuce yield and total radiation upto 500 $cal/cm^2/day$.

Allingham *et al.* (1985) developed a new polyethylene sheet for protected cultivation. By the introduction of additive to polyethylene sheets the IR radiation transmittance was reduced and the diffusion of transmitted light and hydropohobicity increased. In a greenhouse covered with this new material (Infrasol 266), the air, soil and leaf temperatures and plant photosynthetic activity were higher and crops were earlier and higher than under conventional PE.

Abou-Hadid and El-Beltagy (1988) from their studies indicated that radiation under plastic was about one-third or the open field radiation.

Lalu and Stanley (1989) evaluated the solar radiation transmission and capture in single-span greenhouses by means of computer modeling and simulations. The quantity of solar radiation incident on an inner surface is governed by the geometry of the greenhouse through the interception factor for direct radiation and configuration factor for diffuse radiation. Simulated results were found to agree reasonable well with actual data obtained from a shed-type glasshouse and a conventional glasshouse. Computer runs using long-term average solar radiation data revealed that the greenhouse shape and cover material had an obvious effect on the effective transmissivity of the greenhouse. Results of the study would be useful in applications where the monthly average solar radiation level inside the greenhouse enclosure needs to be accurately estimated for design purpose.

Hasson (1990) during the analysis of radiation components over bare and planted soils in green house concluded that the irradiance inside would be proportional to the irradiance outside throughout the day.

2.1.1.2.4 Light

Light is one of the most important climatic factors for any vital processes of the plant. It is indispensable for the photosynthesis. Light regulates the rate of transpiration by controlling the opening and closing of the stomata. The factors such as intensity, quality (wave length), duration (photoperiod) and direction affect plant growth. Maximum photosynthetic rate of different plants will be at different intensity of light.

Light affects yield and growth parameters of plants to a great extent. The degree of dependence varies from plant to plant. Therefore for the proper selection of the shading material and shading percentage for each crop, the light transmittance characteristics of different shading materials available as well as the response of each to different intensities of light should be studied in detail. The various works conducted in this regard are given below.

Huyskes (1971) and Large (1972) reported that lettuce and spinach are normally grown in the temperate zone, under poor light conditions.

Campbell *et al.* (1975) and Soffe *et al.* (1977) suggested the feasibility of pre programming light energy input for maximization of plant growth on a per unit energy cost.

Vince-Prue (1975) and Smith (1976) demonstrated the altered plant growth and development in numerous investigations where plants were exposed to different light intensities and photoperiods.

Craker and Seibert (1982) studied the effect of various light intensities and photoperiods on the growth of lettuce and radish to determine the pattern of light treatments that induce the most growth of these plants with the least input of light energy. Maximum plant growth per unit of light energy occurred under low light intensities and long photoperiods. Using data from radish plants harvested after 15, 20, 25 and 30 days growth, a family of curves predicting the light energy required for growth of different sized radish roots under 16 h days was constructed. Use of plant growth curves as constructed will enable growers to predict crop production per unit of light energy inputs and selecting lighting combinations for the best utilization of available light energy. Results suggested the feasibility of pre programming light energy input for maximization of plant growth on a per unit energy cost.

Henning (1982) during his study on the influence of different glazing materials on the light transmittance of greenhouse found that it is possible to raise the light transmittance of greenhouses by using specially treated plastic materials.

Smith *et al.* (1984) analysed the environment inside a plastic tunnel with and without 30 per cent shade cloth, and in shade houses with 15 and 40 per cent shade cloth and their effect on tomato and cucumbers were measured. The total radiant density, the radiant flux density and radiant spectra were typically reduced by the plastic and different density shade cloths. In April, outside radiant flux densities reached 750 W/m^2 being reduced to 450 W/m^2 under plastic and 300 W/m^2 under 30 per cent shade cloth.

Anderson (1985) from the studies on the influence of light quality in controlled environment found that light quality or specific energy distribution is an important factor.

Chandra (1985) reported that plants growing in the open fields become light saturated at about 32,280 lux assuming that all leaves were exposed to the same intensity. The radiant flux density of full sunlight varies from 86,080 lux to 1,07,600 lux on a clear day. In energy units, the requirement is 80 to 120 Watt/m plant height.

Weimann (1985) in his study on the light transmissivity of different film coverings on greenhouses reported that transmissivities differ between 52 per cent and 71 per cent of the outside radiation and depends on the age, and the layers of the film and the greenhouse construction.

Coffin *et al.* (1987) measured the transmittance of solar radiation into scale models of multispan greenhouses for one year under a wide variety of climatic conditions. Models of conventional greenhouses which were oriented east-west or north-south and glazed with clear or diffuse glass, and models of two prototype multispan insulated greenhouses, oriented east-west with the north-facing roof sections insulated, were tested. The east-west greenhouse models had higher overall light levels than the north-south during the winter months. The insulated greenhouses had moderate reductions in light levels during the winter when compared to conventional models.

Ting and Giacomelli (1987) presented the result of PAR transmission of four different greenhouse glazing, measured at both the glazing and crop canopy levels. The glazing studied were single glass, double glass, tin walled acrylic and air inflated double polyethylene. The comparison between total solar radiation transmission and PAR transmission in the double PE greenhouse was also reported.

2.1.1.2.4.1 Effect of Light on Growth of Plants

Kraybill (1922) observed decreased fruit bud formation in apple and peaches under shade.

Watanabe (1959) reported that high temperatures, natural day length and heavy irrigation increased vegetative growth, but did not affect flower bud development in tomato seedlings. At low light intensities a longer time was required for flower bud differentiation. The number of leaves to the first inflorescence was affected by low temperature, but did not by day length or irrigation. The number of flower buds and the degree of flower development were affected by light intensity, day, length and irrigation.

Beinhart (1963) concluded that increased light intensity resulted in increase branching in white clover.

Hussey (1963) tested the effect of different light intensities on the growth of tomato. Tomato seedlings were grown at constant temperatures of 25°C and 15°C at light intensities of 1600, 800 and 400 f.c.. The rate of enlargement of shoot apex increased with light intensity. The number of leaves was much higher at lower light intensities.

Mattei (1967) and Mattei *et al.* (1973) conducted outdoor shade experiments on lettuce in summer in Rome and the best growth was noticed at 50 per cent of full sunlight. Cooper *et al.* (1969) observed that in the case of tomato, shading either decreased or had no effect on main stem extention rate.

Boyer (1974) found that the number of flowers per tree was 60 to 70 per cent more in cocoa in moderately shaded trees than in unshaded trees.

Graman (1974) observed that decreasing the amount of photo synthetically active radiation by 40 to 60 per cent by shading in bean plants resulted in decreased production of flowers, though it decreased the shedding of young pods.

Allen (1975) noticed that soybeans grown under 70 per cent shade grew much taller (120 cm) than those in the open (80 cm).

Aclan and Quisenberg (1976) reported that in ginger higher light intensity reduced plant height.

Tarilla *et al.* (1977) reported that in cowpea, plants under shade were taller than those in the open and higher light intensity increased the number of branches.

Sansamma George (1981) studied the shade response of legumes. In cowpea, there was no significant difference in plant height due to different shade levels at any of the growth stage. The number of branches at all the growth stages of plant growth was reduced significantly by shading. In black gram, shading failed to have any significant influence on plant growth at any growth stage. Branching was significantly affected by shading at all the stages. During the first 30 days of plant growth, only the plants grown in full sunlight had branches. Between 30^{th} and 60^{th} day, shaded plants also branched, but with intense shading of 75 per cent, most of the plants remained single stemmed throughout the growth period. In groundnut, plant height increased with increasing intensities of shade at all the stages. At all the stages, the number of branches was significantly higher in the open. In red gram the heights recorded was maximum for the plants receiving full illumination and it decreased steadily with increasing intensities of shade. The plants in the open had significantly higher number of branches when compared to the shaded plants.

Lalitha Bai (1982) conducted an experiment to study the shade response of sweet potato, coleus, colocasia, turmeric and ginger. Based on the results obtained, sweet potato was classified as shade sensitive, coleus as shade intolerant, colocasia as shade tolerant and ginger and turmeric as shade loving. Expecting colocasia, plant height in all the crops increased and number of branches decreased significantly with increasing intensities of shade.

Based on the experiments conducted by El-Aidy and El-Afry (1983) on the influence of shade on growth and yield of tomatoes cultivated during the summer season, concluded that the increased shade intensity will significantly decrease the number of tomato leaves.

Krishnankutty (1983) conducted an experiment to study the shade response of some common vegetables. Based on the shade response, brinjal was classified as shade intolerant and bhindi, cluster bean, amaranthus and vegetable cowpea as shade sensitive. In the case of bhindi, there was stunting of plants in shade. Branching in all the crops was significantly suppressed by shade.

Glenn *et al.* (1984) studied the seasonal effects of shading on growth of greenhouse lettuce and spinach. Lettuce and spinach were grown under various shade treatments. Six experiments were conducted with lettuce and five with spinach at different times of the year. The objective was to compare their growth potentials over a wide range of PAR from natural sunlight. Lettuce responded positively to PAR upto the highest level measured 45 mol/m^2/day. The maximum growth rate was 0.221 g/g/day from day 14 to day 42 after seeding. Spinach was PAR saturated at approximately 25 mol/m^2/day. The ground cover of a plant per unit dry weight increased at low PAR levels, and spinach had a 4-fold greater ground cover per unit weight than lettuce at all PAR levels.

Smith *et al.* (1984) noticed that shaded plants adapted to their environment by producing a greater leaf area, but smaller root system, associated with which was an increased resistance to leaf water movement. Shaded cucumber produced less total dry matter and proportionately put more dry matter into leaves and stems and less into roots and fruits.

In the study conducted by Hinsley (1986) to examine the influence of shading on growth of Frazer Fir transplants in an irrigated transplant bed, it was found that the stem diameter as well as shoot elongation were virtually identical in full sunlight and 30% shade and decreased significantly fewer than 76% shade. Diameter and shoot elongation were 70% to 75% greater in full sunlight than at fewer than 76% shade.

Rylshki and Spigelman (1986) analyzed the effect of different levels of shading on sweet pepper under high solar radiation at two different spacing during the summer months. When light intensity was reduced, plant height, number of nodes and leaf size increased.

El-Gizawy and El-Habbasha (1989) carried out a field trial during the late summer on tomato plants to study their performance under shading in Egypt. They found that increased shading significantly increased plant height and leaf area. The number of days from sowing to flower appearance increased as the shading level increased.

Zanon (1990) remarked that photosynthesis measured as released CO_2 depends on the light intensity and increases with luminosity. The increase was found in a definite range beyond which there was no effect.

Armitage and Ki-Cheolson (1992) studied the influence of shade and photoperiod on some cut flowers. Plants of blue spirea were evaluated as cut flowers in the field and in the greenhouse. In the field, yield and stem diameter were similar in full sun and in 55% shade. Stem length, however significantly increased under shade. The average stem length was 64.5 cm under 55% shade where as it was 58.4 cm in full sun in 1988 and in 1989; it was 57.5 cm and 48.5 cm respectively.

2.1.1.2.4.2 Effect of Light on the Yield

Freeman (1929) in the earliest recorded field experiment to determine the optimum degree of shade for cocoa reported that lightly shaded cocoa gave higher yield than those under intense shade.

Watanabe (1959) reported that in tomato maximum early yield and total yields were obtained from plants grown under natural day length conditions at 20-25°C.

May and Anticliff (1963) conducted two shading experiments on Sultana vines, a preliminary one in which shades of different intensities were used during October and November, and a main experiment in which shades reducing light intensity by about 70% were applied for different lengths of time between October and January. In the season of shading, bunch weight was reduced because of smaller and possibly fewer, berries by shades of greatest intensity in the first experiment. In the second, shades in position later than 8th December reduced berry size, and yield was depressed when shading lasted for at least six months. In the season following shading, fruitfulness and consequently yields were severely depressed where light intensities had been reduced by about 70% for at least four weeks between early November and mid-December. The only other yield component affected was sugar concentration of the berries which was increased where fresh yield was depressed, but not enough to prevent the depression of dried yield also. It was concluded that light intensity is an important factor for fruit bud formation in the Sultana. Reduction of light is inhibitory, but only during the period of inflorescence initiation.

Edmond *et al.* (1964) conducted experiments in tomato and maximum yield was obtained from plants receiving only 45% of full sunlight.

Aono *et al.* (1976) observed that shading tea bushes to about 45% light intensity with cloth screen about 60 cm above the plucking table depressed new shoot growth and yield. It was also found that the shade intensity was inversely related to yield and this decrease in yield was highest during the first plucking season.

Pallis and Bustrillos (1976) found that in sorghum, grain-straw ratio decreased with increase in shading from 0 to 50%.

El-Aidy and Moustafa (1977) made a comparison between the growth and yield of the plants under plastic and in the open field to test the effect of using plastic under their local conditions with tomato plants. The results which were obtained during the early stage indicated that using plastics for 4-5 months (December – March) increase tomato yields six times during the period of March and April. They also conducted experiments on cucumber and reported that when cucumber was grown under plastic tunnels in winter, the yield was 4.1 kg/cm^2 during the end of January to the end of March under El-Sheikh climatic conditions.

Wahua and Miller (1978) observed that seed yields of soybean plants shaded to reduce sunlight by 20, 47, 63, 80 and 93 per cent were 90, 75, 48, 18 and 2 per cent respectively, of that obtained from unshaded plants. They also found that the seed yield was highly and negatively correlated with shade.

Joseph (1979) noticed that the tea under shade gave much higher yield than in exposed plots.

Radha (1979) observed that the fruit weight of pineapple with crown was not influenced by shading. But the contribution of crown to the fruit weight increased as the intensity of shade increased.

Sagi (1979) studied the influence of solar radiation intensities on flowering, fruit set and fruit development in tomatoes and reported that tomato was sensitive to low light intensity regarding flower and fruit malformation, but which gave the highest yield when grown under 25% shade.

Wong and Wilson (1980) from the studies on the effect of 60 and 40 per cent of full sunlight increased the shoot yield by 30 and 27% respectively.

Lalitha Bai (1981) noticed a drastic decrease in yield of sweet potato, while in colocasia the decrease in yield was not marked upto 50% shade intensity. Coleus showed a linear decrease in yield almost in proportional to the increase in shade intensity. Turmeric and ginger gave maximum yields at 50 and 25% shade intensities respectively.

Sansamma George (1982) noticed that the grain yield of cowpea fell substantially when shaded. In black gram the grain yield was significantly affected by shading. When expressed as the percentage of the yield in the open, the yields at 25, 50 and 75% shades were 35.2, 26.0 and 0.5% respectively. in groundnut the yields at 25, 50 and 75% shade were 34.8, 19.7 and 11.9% respectively when expressed as percentage of yield in the open.

Krishnankutty (1983) reported that bhindi, cluster bean, amaranthus and vegetable cowpea showed a drastic decrease in yield with increasing shade intensity while in the case of brinjal the decrease in yield was almost in proportion to the increase in shade intensity.

El-Aidy (1984) conducted a research on the use of plastic and shade nets on the yield of tomatoes. They used shade nets from June to the end of August. The results indicated that there were no significant differences between the shading treatments and control in the first season, but they were significant in the second season only. However, plants grown under shade tended to produce higher fruit yields than those in the open, but such tendency was reduced with the increase in the amount of shade, 40% shade was the best in this respect.

Glenn (1984) reported a high statistical correlation between lettuce yield and total radiation upto 550 cal/cm^2/day.

Chella and Schapendonk (1984) in their studies on the quantification of the effects of light reduction in greenhouses on yield found that the effect of light on the growth of young plants was less, while the rate of production of older plants was approximately proportional to light except for low irradiances.

Guttormsen (1984) compared the yields using various types of plastic covers or leaving the crop uncovered. The types of cover used were standard polyethylene film, perforated or slitted polyethylene film and spun polypropylene fabric. On early potatoes, spun fibre gave the least increase in yield compared with the uncovered crop; while the standard polyethylene film gave the greatest.

The yield under perforated film was greater than anticipated. Perforated film applied early resulted in increased yields.

Smith *et al.* (1984) compared the yield of tomato growth under 15% shade, plastic, 40% shade and in the open. Tomato yields were best under 15% shade in comparison to under plastic, 40% shade and in the open.

El-Aidy (1986) evaluated the possibility of commercial tomato production under different sizes of simple plastic tunnels in winter and under different shade level nets in summer. Plastic walk-in-tunnels provided to be technically and statistically satisfactory. Plants grown under shade tended to produce higher fruit yields than those in the open field, but such tendency was reduced with the increase in the amount of shade, 40% shade being best in this respect.

Rylshki and Spigelman (1986) reported that in sweet pepper the changes in plant development due to shading affected fruit set, number of fruits per plant, fruit location on the plant, fruit development and yield. The lowest number of fruits per plant was obtained under 47% shading at 5 plants/m^2 density and under 26% shading at 6.7 plants/m^2 density. Under shading, individual fruits were larger. Shading reduced sun-scald damage of the fruits from 36% in full light to 3-4% under 26 and 47% shading. The highest yield of high quality fruits was obtained with 12-26% shade. They also investigated shading as a treatment to delay fruit development of sweet red pepper and to protect them from excessive radiation. In one experiment, the plants were grown throughout the growth season in screen houses (25% shade), while in the other experiment plants were grown in the open, and shaded (18 or 30% shade) only after the fruits on flowering nodes 1-2 were already at the green-ripe stage. The first method of shading postponed the time of fruit plucking by about 1 month, and the second method by 11 days. With the first method, fruit growth and ripening, and with the second ripening only, were slowed down, leading to a larger yield of top quality fruits. Growing under screen houses for the entire season led to better developed plants, bigger fruits and a total higher yield.

Koning (1988) conducted a glasshouse trial with tomatoes. The overhead screens of aluminium slats with 42% light intensity were closed when the light intensity in the glass house attained 450, 550 and 650 W/m^2 and effects on yield from mid June to September were assessed. Total light loss with the three treatments amounted to 20, 15 and 10% respectively; the corresponding loss in yield was 7, 5 and 3% respectively with no shading. Data were also graphically presented on the photosynthesis of a tomato leaf at light intensities from 0 to 200 W/m^2.

Lagier (1988) in his studies on the effect of shading on the quality of tomatoes grown under plastics in the Mediterranean region found that yields were generally lower under shade although average weight was higher.

Zhong and Kato (1988) studied the effect of shading on solanaceous fruits. In pot trials, tomatoes, eggplant and sweet peppers were grown in a greenhouse with natural sunlight, 35% shading or 55% shading and the yield was investigated. Decreasing the light intensity decreased dry weight and fruit yield with greatest effect in tomatoes and the least effect in sweet pepper.

Armitage (1989) reported that shade will influence the stem length of cut flower species and may or may not influence yield, depending on species.

El-Gizawy El-Habbasha (1989) noticed that the maximum yield of tomato was obtained at 35% shading. The quality of fruits was also higher at 35% shading.

Norberg *et al.* (1993) investigated the effect of shading and crop cover on meadow form oil yield and reported that the shade increased seed yield 35%, seed oil content 8% and oil yield 47%. Early cover increased seed yield 21% and oil yield 33%.

Materials and Methods

MATERIALS AND METHODS

This chapter presents the installation of the shading structures and the various experiments carried out in it.

3.1 Site Selection

The site selected was on the western side of the farm office building at the Instructional farm, K.C.A.E.T., Tavanur. The place is situated at 10° 53' N latitude and 76° E longitude.

The absence of buildings or any other obstruction around the site which would have cast shadows was a criterion for the site selection. Adequate supply of fresh water was ensured. The site was well drained. The land was surveyed to ensure enough area for the installation of all the structures with the same orientation, parallel to each other.

3.2 Orientation

Orientation is important to obtain maximum solar radiation. East-West oriented structures maintain better light level compared to north-south oriented. Hence all the structures were oriented east-west parallel to each other. Enough space was left in between the structures so that the shadow of one will not fall on the other.

3.3 Size and Shape of the Structures

The size of the structures to be installed was selected to be 6m x 4m x 2m. The shape resembles the traditional shading pandals i.e., rectangular with flat top.

3.4 Installation of the Shade Structures

3.4.1 Site Preparation

The site was cleared and leveled well before installing the structures. Four 6m x 4m rectangular plots were marked on the cleaned area orienting the longer dimension in the east-west direction. These were the plots to be shaded. A similar plot was marked outside the area to be shaded with the same east-west orientation. This was the plot for testing crops under full sunlight condition.

3.4.2 Structural Members

The structural members consisted of poles, wooden framework on the top, stay wire and shade net. G.I. pipe of 1¼ inch diameter and 2.5 m length were used as the poles for giving the structural stability to the structures. Stay wire was used along with wooden framework to give additional support to the net.

3.4.3 Foundation

These were meant to provide a firm support to the structure. To ensure stability to the framework, the pipes were inserted to the holes in the ground and grouted.

3.4.4 Construction Procedure

Four structures of size 6m x 4m x 2m were constructed. Four corner points of the four rectangular plots were staked. Holes of 2.5 cm diameter were made at 2 m intervals along the longitudinal rows. Care was taken to see that the holes ran parallel. G.I. pipes were placed in the dug holes and fixed by grouting.

The wooden framework was firmly fixed on the top. Stay wire was tied connecting the members of the wooden frame work. This provided additional support to the shade net. At a depth of 0.5 m from the top, the poles were connected by means of stay wire. The three dimensional view of the structure is shown in Fig. 1.

The shade nets were spread over the structures from one end to the other without wrinkles. The nets were extended to 0.5 m along all the sides and were stitched firmly to the wires. This prevented the sagging of the nets.

Green and black shade nets were tested. Both these nets were available of two different shading percentages. They were designated by the manufacturers as green net of 50% shade (G50), green net of 75% shade (G75), black net of 50% shade (B50) and black net of 75% shade (B75). Using these four types of nets, four shade houses were constructed. An overall view of the experimental site is shown in Plate 1. The materials used and their costs are given in Appendix I.

3.4.4.1 Shade Nets

The shade nets were manufactured from High Density Polyethylene plastic. They were treated with best known ultraviolet stabilizers in the highest possible concentration that are upto the latest technical knowledge. This ensures long life of the product. The nets are durable for more than four years even if they were exposed to sun, rain etc. Shade nets are available in different colours and different shading percentages. Green and black shade nets of 50 and 75% shades were used in this study.

3.5 Experimentation

The experiments were conducted during the summer months of 1995. The environmental parameters were monitored for ten weeks starting from 1st March. The readings were taken daily at one hour interval from 7.30 am to 5.30 pm.

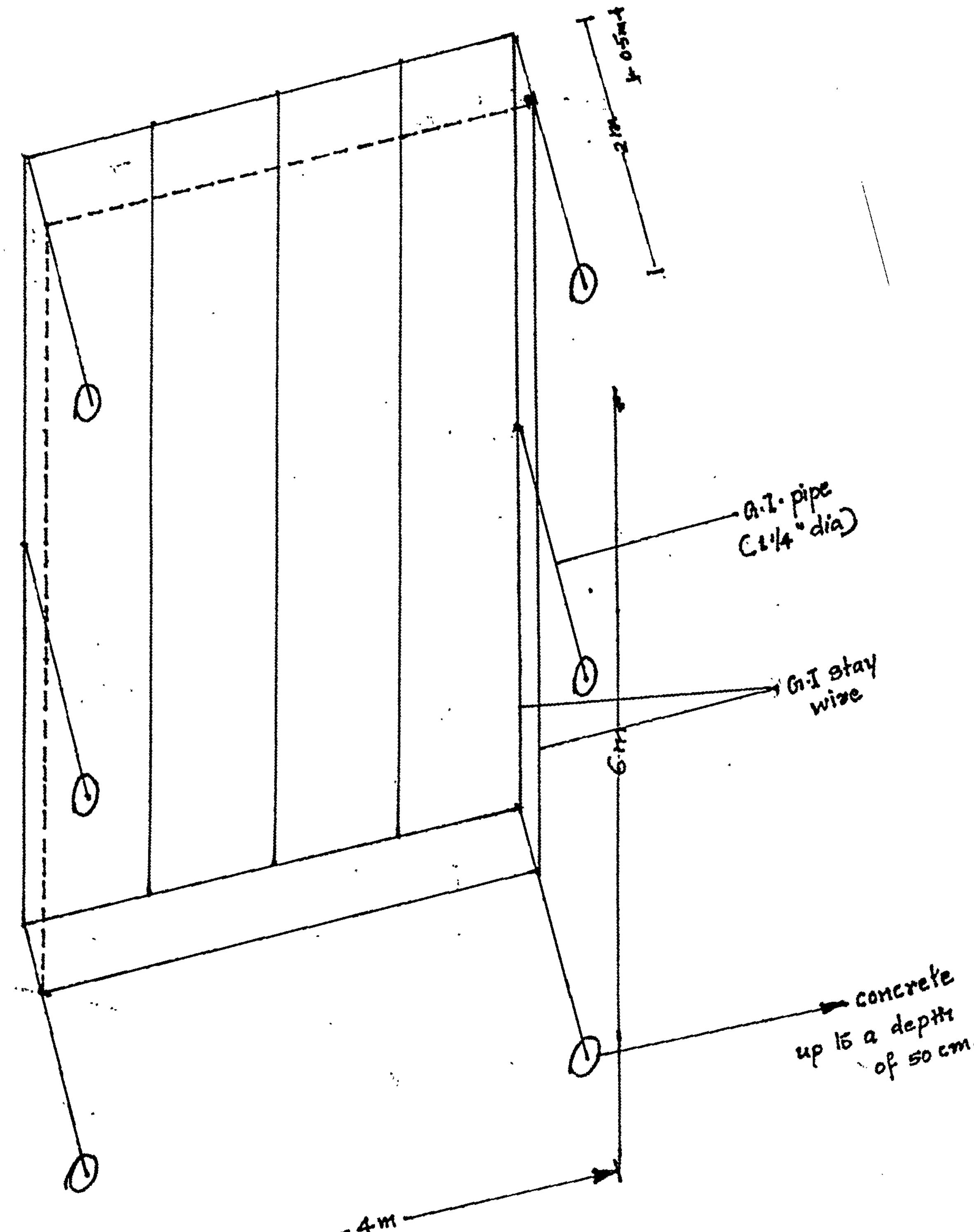

Fig.1 Three dimensional view of the shade structure.

Plate 1 – An overall view of the experimental site

Plate 2 – Temperature measurement using thermometers

The parameters monitored included dry bulb temperature, wet bulb temperature, intensity of solar radiation and intensity of photosynthetically active radiation. All the parameters were monitored inside and outside the shade structures. Two crops were tested inside the shade nets and in the open field. The growth parameters monitored included plant height, stem diameter, number of leaves and number of branches.

3.5.1 Experimental Set-up

Four shading structures were constructed. Wet bulb and dry bulb thermometers were suspended at the middle of all the structures at the same height above the ground. A dry bulb thermometer and a wet bulb thermometer were also suspended in the open. All the thermometers used were of the range 0 to 50°C. It was confirmed that all the thermometers read accurately. Solar radiation intensity was monitored using a solar radiation monitor. The same instrument was used for monitoring the solar radiation intensity inside all the shade nets and also outside. A digital Lux meter was used for monitoring photosynthetically active radiation inside and outside the shade nets.

3.5.2 Monitoring of Environmental Parameters

3.5.2.1 Temperature

The temperature measurement using thermometers is shown in Plate II. The dry bulb and wet bulb thermometer readings were taken daily for ten weeks starting from March 1st at one hour interval from 7.30 am to 5.30 pm. The readings were recorded inside the four shading nets and also outside. The dry bulb thermometers indicate the inside and outside temperatures at all these times.

Using the psychrometric charts, the relative humidity inside the shade nets and outside at all the times were determined from the dry bulb and wet bulb temperatures recorded.

3.5.2.2 Intensity of Solar Radiation

Intensity of solar radiation was measured using a solar radiation monitor. Specifications of this instrument are given in the Appendix II. The solar radiation intensity was noted at one hour interval during the day time from 7.30 am to 5.30 pm. At all the times, the readings were taken inside and outside the four shade nets.

3.5.2.2.1 Solar Radiation Monitor

The solar radiation monitor used is shown in Plate III. Solar radiation monitor indicates the solar radiation (total range) in watts/m^2/sec. The instrument consists of a remote operated sensor and a meter. The sensor is to be kept facing vertically upwards at the place where the intensity of solar radiation is to be recorded. The cable connecting the sensor and the meter can be extended for a hundreds of meters without any adjustment. This enables the installation of the sensor at remote places. The meter can be permanently kept inside the building or taken to the site as needed. The sensor converts solar radiation to electrical signals while the meter displays the signals after conversion to solar radiation in watts/m^2. This instrument operates on 9v dry cells.

Automatic recording is also possible with this instrument. For this, a paper chart recorder is to be connected to the REC output in the range 0-100 mv.

In this experiment since only one instrument was available, the solar radiation intensity was measured by keeping the meter with the sensor at each place at each time. The readings were recorded manually.

Plate 3 – Solar radiation monitor

Plate 4 - Luxmeter

3.5.2.2.1.1 Operation

1. Keep the sensor at the place of measurement with the sensor facing upwards.

2. Switch on the meter (without connecting the sensor). The meter should indicate ZERO. Any difference, if it is less than 1% of the range, may be neglected. Otherwise it may be adjusted inside by adjusting the present marked ZERO or the difference can be added or subtracted, as the case may be, from the final value.

3. Connect the sensor. The meter will indicate the solar radiation in watts/m^2.

3.5.2.3 Intensity of Photosynthetically Active Radiation

Light energy is the solar radiation in the photosynthetically active radiation (PAR ie, 0.4 to 0.7 microns) range. It is indispensable for the photosynthesis of plants. The PAR intensity was measured using a digital Lux meter. The unit of measurement was lux.

3.5.2.3.1 Lux Meter

Lux meter measures the intensity of solar radiation in the PAR range. Plate IV shows a Lux meter. It measures the light intensity in lux or in foot candle. The specification of the instrument is given in Appendix III. The instrument consists of a meter and a sensor. This sensor is to be kept facing upward at the place where the intensity of light is to be measured. The sensor converts the PAR into electrical signals while the meter displays the signals after conversion to radiation in lux or in foot candle.

3.5.2.3.2 Measuring Procedure

(1) Determine the unit lux or ft. candle on the switch. Determine the response time, typical select to the 'SLOW' position.

(2) Select the maximum range on 'RANGE SWITCH'.

(3) The meter indicates the intensity of light in lux or in foot candle. If need hold the display value, then slide the 'DATA HOLD SWITCH' to the 'ON' position.

3.5.3 Testing of Crops

Two crops namely tomato and amaranthus were tested under the shade nets and in the open field to study the effect of using plastic shade nets under local conditions during summer.

3.5.3.1 Tomato

Tomato was grown under the green and black shade nets of two different shading percentages and in the open field. This crop was tested during period of February-April.

Seeds were sown on 16.01.95 in well prepared nursery beds. Irrigation was ensured daily. Seedlings were transplanted on 26.02.95 after they attained a height of 10 cm.

The plots under three shade nets and in the open field were divided into two halves. Four furrows were made at a spacing of 60 cm in the eastern half of all plots, after leaving a space of 0.5 m width at all the boundaries. Tomato seedlings were planted in these furrows at a spacing of 60 cm.

Fertilizers were applied at specified dosages at required times. Weeding was also done frequently. Irrigation was done daily in the evening.

3.5.3.2 Amaranthus

This crop was tested during the period of April-May. In nursery beds, seeds were sown on 05.03.95 and were transplanted to the field on 26.03.95.

The seedlings were planted in the furrows made with a spacing of 25 cm. fertilizers were applied and weeding was done, when needed. Irrigation was ensured to this crop also daily.

3.5.4 Physiological Observations

To study the effect of different shadings on the physiological parameters of crops, the growth and yield were tested in comparison to this crop grown in full sunlight.

3.5.4.1 Growth Parameters

The measured growth parameters include plant height, stem diameter and number of leaves per plant. One plant was selected from each furrow for measurement. Thus under each condition, four plants of tomato and four of amaranthus were selected.

In tomato, the stem diameter and plant height were measured at approximately 10 day interval during the active growth stage and the number of leaves per plant were also counted and recorded. These observations were taken on 05.03.95, 17.03.95, 26.03.95 and 10.04.95.

In amaranthus, the observations were taken on 05.04.95, 15.04.95, 25.04.95 and 04.05.95. The observed parameters included plant height, stem diameter and number of leaves per plant.

3.5.4.2 Yield

Due to the unexpected pre-monsoon rain during the month of May, the tomato plants wilted suddenly due to fungal attack. So the yield of tomato couldn't be recorded. The yields of amaranthus grown under shade and in the open field were measured. The weight of four plants, together were taken under each condition and were recorded.

3.5.5 Variation of Environmental Parameters under Shade

The variation of environmental parameters under the four different shades were studied by comparing the observed temperature, relative humidity, solar radiation intensity and light intensity data under the shades with that in the open field.

From the consecutive seven days data, weekly means were calculated at 7.30 am to 5.30 pm for the ten weeks of observations. The daily variations in environmental parameters were plotted. These were studied in detail to determine the effect of the four tested shade on the environmental parameters such as temperature, relative humidity, solar radiation intensity and intensity of PAR.

3.5.5.1 Regression Analysis

Linear regression technique was used to develop relationships between the environmental parameters in the open and those under the four shade nets. Regression analysis was performed on the nine week data. Equations were developed to predict the inside parameters based on the outside conditions.

The developed equations were used to predict the data for the 10th week. The predicted data for this week was compared with the observed data. Observed vs predicted plots were made for easy comparison to determine the accuracy of prediction using the developed equations.

3.5.6 Variation of Physiological Parameters under Shade

Four plants from each plot were selected for observations. The mean values of these observations were taken under each condition. These mean values of plant height, stem diameter and number of leaves were then plotted against time to determine the effect of shading on the growth of tomato and amaranthus.

The yield of amaranthus under the different shades and in the open were also plotted and compared.

Results and Discussion

RESULTS AND DISCUSSION

At present, there is an increasing trend in growing crops under controlled environment systems. Knowledge of the microclimate under different shading nets is a must to utilize the potential of this technology to the maximum possible extent.

Air temperature, relative humidity and solar radiation as climatological elements play an important role in the evapotranspiration from different crops. Hence the characteristics of these elements have been studied in order to provide a database of ideal growing conditions for different plants.

Solar radiation and photosynthetically active radiation received under shade nets depend on the transmissivity of the net material and the percentage of shading. Studies on the hourly variation in solar radiation intensity and light intensity inside and outside the shade nets were conducted.

The variation in temperature, relative humidity, solar radiation intensity and light intensity under the green and black shade nets of 50 per cent and 75 per cent shading were studied for comparing the performance of these shade nets. The results of these studies were enunciated in this chapter.

4.1 TEMPERATURE

Weekly average values of daily outside temperature at one hour interval from 7.30 a.m. to 5.30 p.m. for the ten weeks of study are given in Table 1. The corresponding temperatures under the G50, B50, G75 and B75 shade nets are given in Tables 2, 3, 4 and 5 respectively. Figures 2 and 3 shows the variation in temperature under the shade nets and in the open space during the I and X weeks of study.

Table 1. Weekly average daily outside temperature from 7.30 am to 5.30 pm during the 10 weeks from 01.03.1995 to 09.05.1995.

	Temperature (°C)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	24.80	28.10	32.30	35.60	36.70	37.50	38.20	37.40	35.20	32.80	31.30
II	26.10	28.80	32.50	33.70	36.70	37.80	38.30	36.80	35.80	33.30	32.20
III	26.50	29.60	32.60	35.50	38.90	37.80	39.20	37.90	36.00	34.50	33.00
IV	26.50	31.50	34.10	35.60	36.60	35.50	37.70	37.50	35.50	33.80	31.30
V	27.30	30.80	34.10	36.10	38.00	38.20	37.10	37.20	36.00	34.40	32.20
VI	28.10	30.80	34.10	36.30	36.90	37.50	36.90	36.10	35.60	34.20	32.62
VII	30.00	33.90	36.00	38.20	38.10	35.90	37.50	36.50	36.00	34.50	32.40
VIII	28.30	31.30	34.40	35.30	35.90	35.30	37.00	35.80	35.60	34.60	32.60
IX	26.20	29.50	33.90	35.10	36.00	36.60	34.80	35.40	32.80	33.90	32.40
X	27.50	31.20	34.10	35.20	36.70	36.60	35.40	36.10	34.60	33.20	32.10

Table 2. Weekly average daily temperature from 7.30 am to 5.30 pm under G50 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.

Temperature (°C)											
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	24.60	27.60	30.50	33.50	34.70	35.40	35.50	34.90	33.60	32.00	30.60
II	26.00	28.50	30.50	32.20	34.40	36.00	36.10	34.90	33.90	32.10	31.10
III	26.30	38.90	31.00	33.90	36.50	35.80	37.30	36.10	34.70	33.10	31.10
IV	26.30	29.70	32.00	33.80	34.80	34.10	35.70	35.40	34.00	32.60	30.40
V	27.10	29.80	32.20	34.00	35.80	36.10	35.30	35.50	34.30	32.60	31.30
VI	27.50	29.10	32.60	34.40	35.90	36.00	35.60	34.40	33.60	32.00	31.20
VII	28.50	31.50	34.20	35.20	36.90	33.60	35.30	34.10	34.40	32.70	30.80
VIII	27.50	29.70	32.20	33.30	33.80	33.20	34.60	33.70	33.40	32.10	31.20
IX	25.60	27.40	32.00	33.10	34.20	34.20	32.30	33.20	31.20	32.10	30.70
X	27.00	29.70	32.00	33.30	34.50	34.40	33.40	34.10	32.50	31.60	30.70

Table 3. Weekly average daily temperature from 7.30 am to 5.30 pm under B50 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.

	Temperature (°C)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	25.70	28.60	31.40	34.00	35.30	36.00	36.20	35.50	34.20	32.30	31.00
II	27.00	29.00	31.20	32.90	35.60	36.60	36.80	35.70	34.50	32.70	31.80
III	27.00	29.30	31.70	34.30	37.10	36.80	38.00	36.70	35.40	33.60	31.80
IV	26.90	30.30	32.60	34.50	35.30	34.80	36.20	36.10	34.50	33.30	30.90
V	27.70	30.10	32.90	34.60	35.90	36.60	35.00	36.00	34.80	33.20	31.80
VI	28.30	29.60	33.00	35.10	36.30	36.90	36.10	35.20	34.60	33.10	31.86
VII	29.20	32.00	35.10	36.50	37.50	34.50	36.50	35.30	35.10	33.60	31.30
VIII	28.30	30.40	33.00	34.30	34.80	34.30	35.60	34.60	34.30	33.40	31.80
IX	26.60	28.30	32.80	34.00	34.90	35.10	33.50	34.30	32.20	32.90	31.50
X	27.80	30.30	32.90	34.30	35.70	35.40	34.20	34.90	33.50	32.30	31.30

Table 4. **Weekly average daily temperature from 7.30 am to 5.30 pm under G75 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.**

	Temperature (°C)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	23.80	27.00	29.90	32.80	34.00	34.70	34.90	34.50	33.20	31.60	30.30
II	25.70	28.00	30.00	31.60	33.90	35.20	35.50	34.10	33.20	31.70	30.70
III	26.00	28.30	30.50	32.70	35.70	35.10	36.60	35.40	34.10	32.50	30.40
IV	25.30	29.00	30.70	32.60	33.90	33.60	35.10	34.80	33.50	32.10	29.90
V	26.70	29.30	31.60	33.70	35.20	35.40	34.60	34.90	33.70	32.00	30.70
VI	26.80	28.30	31.70	33.70	35.10	35.10	34.90	33.50	32.60	31.30	30.61
VII	28.00	30.70	33.10	34.40	35.70	32.80	34.60	33.30	33.30	31.80	30.00
VIII	27.00	28.90	31.20	32.50	33.00	32.50	33.90	32.90	32.60	31.40	30.70
IX	25.10	26.90	30.90	32.10	33.40	33.10	31.60	32.50	30.70	31.40	30.30
X	26.30	29.50	31.43	32.70	34.00	33.90	32.90	33.60	31.80	30.60	30.00

Table 5. Weekly average daily temperature from 7.30 am to 5.30 pm under B75 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.

	Temperature (°C)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	24.00	26.90	30.50	33.50	34.50	35.10	35.80	35.10	33.60	31.80	30.70
II	26.20	28.40	30.80	31.80	34.50	35.40	35.90	34.60	33.70	31.50	30.90
III	26.60	28.90	30.90	33.40	36.40	36.00	37.70	36.40	33.90	33.80	31.21
IV	25.90	29.90	32.20	33.50	34.40	34.10	35.60	35.20	33.80	32.80	30.10
V	27.00	29.60	32.10	34.00	35.60	36.00	35.00	35.10	34.00	32.50	31.00
VI	27.40	28.50	32.20	34.40	35.60	35.50	35.40	34.20	33.40	31.80	31.08
VII	28.30	31.20	34.20	35.10	36.60	33.30	35.00	34.00	34.20	32.50	30.70
VIII	27.30	29.50	32.20	33.10	33.80	33.10	34.40	33.50	33.30	32.10	31.20
IX	25.50	27.30	31.80	32.90	34.00	34.10	32.10	33.10	31.10	31.90	30.60
X	26.80	29.80	32.10	33.00	34.60	34.40	33.30	33.90	32.70	31.40	30.50

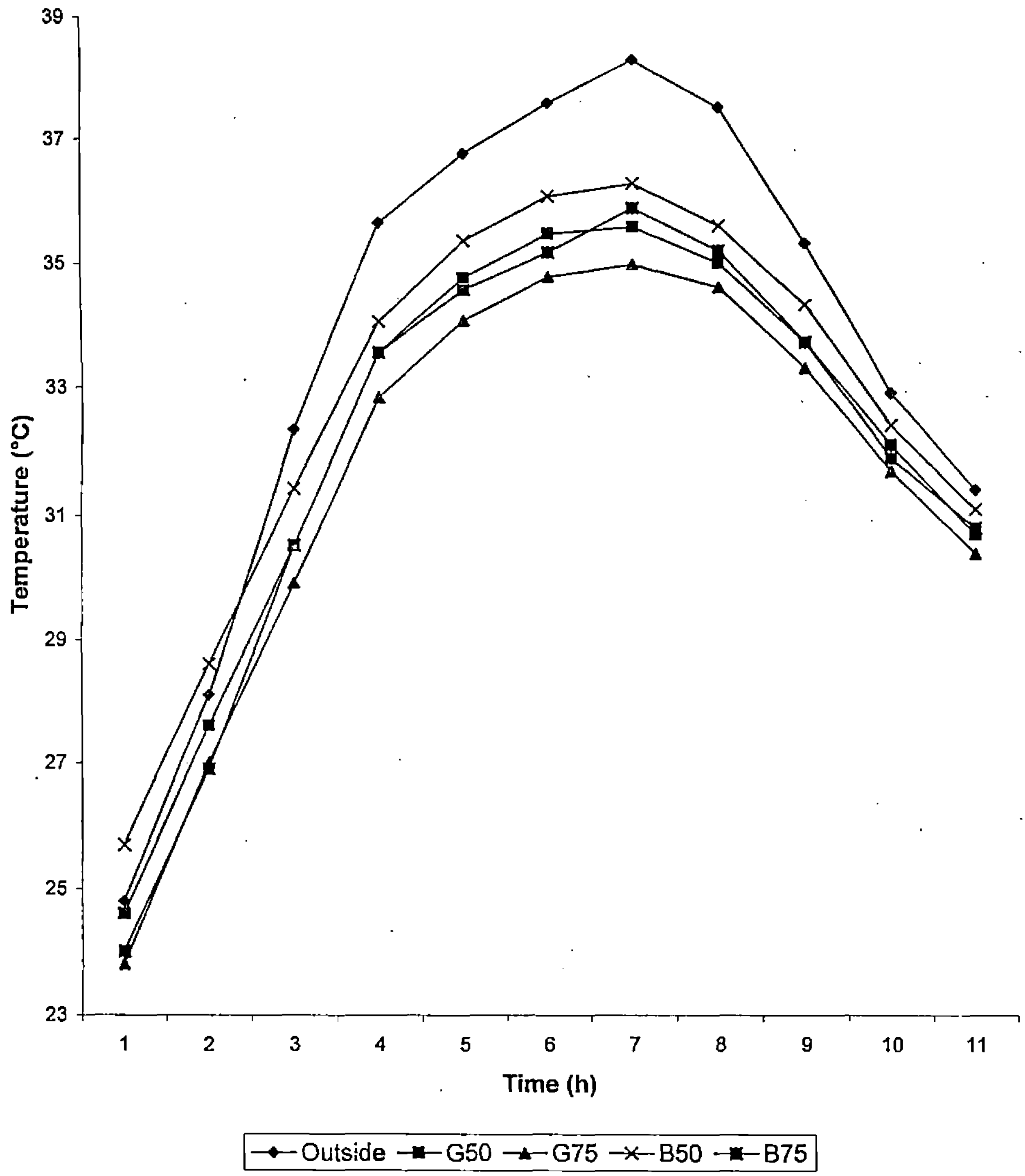

Fig.2. Weekly average daily variation of inside and outside temperature during the I week (1.3.95 to 7.3.95)

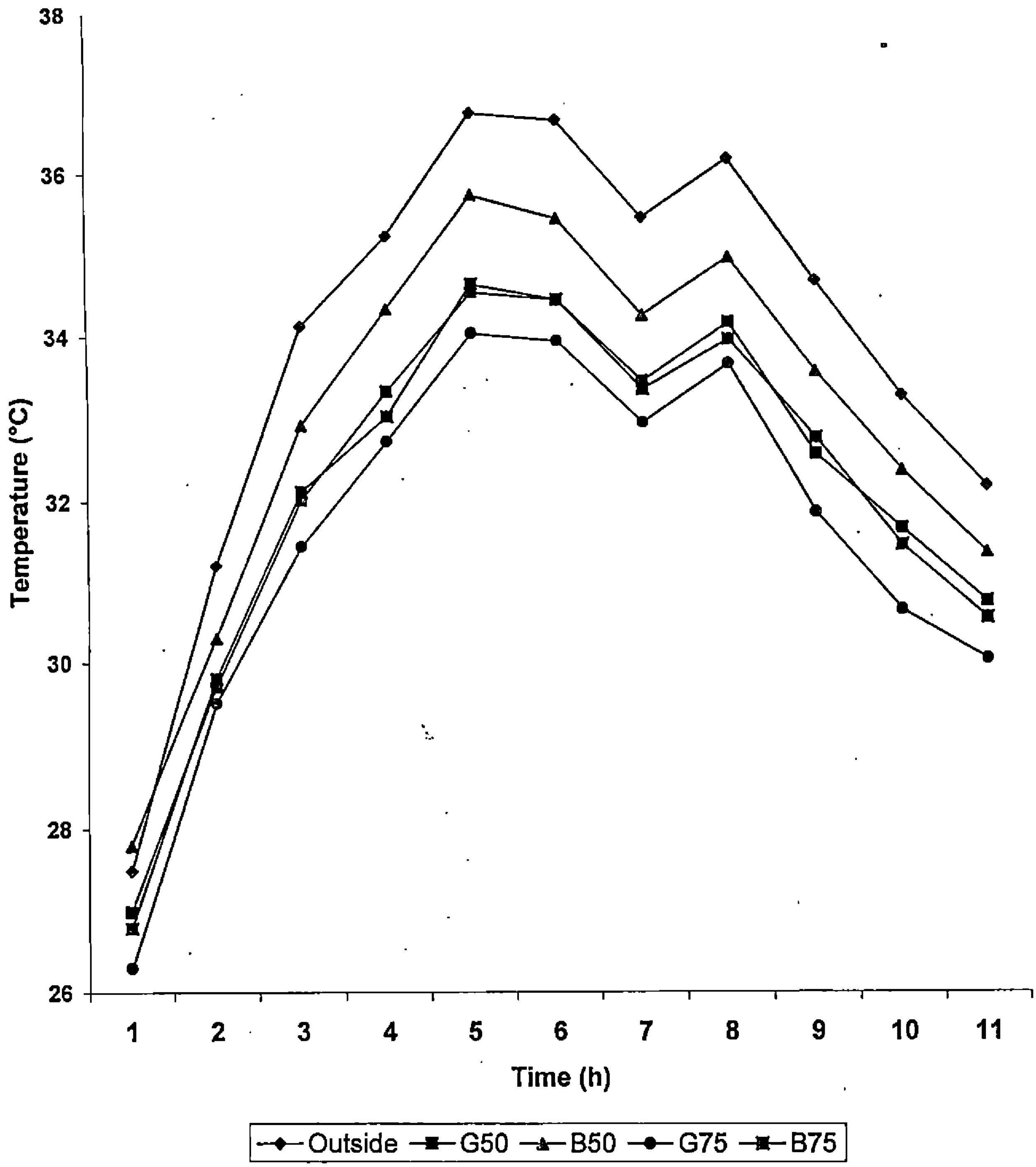

Fig.3 Weekly average daily variation of inside and outside temperatue during the X week (3.5.95 to 9.5.95)

From these tables and figures, it is clear that these shade nets lowered the air temperature, though not much. This lowering was in proportion to the intensity of shading.

Always the temperature under the green shade nets having 50 and 75 per cent shades and black shade net having 75 per cent were lower than the outside temperature. But when the outside temperature is less than 29°C, the black shade net with 50 per cent shade raised the temperature to a small extent. At higher temperatures, this shade net also lowered the air temperature. From the Figures 2 to 3 it is clear that at lower outside temperatures, the lowering of temperature due to shades are less, whereas it increases with increased outside temperatures. Pattern of variation of temperatures under the shade nets were similar to that in the open space.

The G50 shade net lowered the temperature by 0.2-0.8°C, at outside temperatures less than 30°C. At 30 - 32°C temperature in the open space, this shade net lowered the temperature by 1 - 1.7°C whereas at above 32°C, the temperature was lowered by 1.5 - 2.9°C. The minimum outside temperature observed was 24.8°C. The corresponding temperature under the G50 shade net was 24.6°C. At lower range, there was not much variation in temperature due to shade. Corresponding to an outside temperature of 30°C, the inside temperature was 28.5°C. The temperature under this net was 37.3°C, corresponding to the maximum outside temperature of 39.2°C.

At outside temperatures less than 30°C, the temperature under B50 shade net was higher than that in the outside. The increase in temperature varied from 0.2 - 0.9°C. When the temperature in the open space was 28.3°C, there was no variation of temperature due to this shade net. Corresponding to the lowest outside temperature of 24.8°C, the temperature under B50 shade net was 25.7°C. At above 30°C, this net lowered the temperature by 0.3 to 2.1°C. When the outside temperature was 30°C, the temperature was 29.2°C under the net.

Corresponding to the maximum outside temperature of 39.2°C, the temperature under the B50 shade net was 38°C.

Of the four shade nets tested, the maximum reduction of temperature was under G75 shade net. At outside temperature less than 30°C, this shade net lowered the temperature by 0.4 to 1.3°C. The shading was more effective at higher temperatures. This shade net lowered the temperature by 1.5 - 4.1°C at higher outside temperatures. Corresponding to the lowest outside temperature of 24.8°C, the inside temperature was 23.8°C. When the temperature in the open space was 30°C, the inside temperature was 28°C. The maximum inside temperature was 36.6°C. This was corresponding to an outside temperature of 39.2°C.

The B75 shade net lowered the air temperature except in two or three cases. The reduction of temperature was in the range of 0.3 to 1.2°C, when the outside temperature was less than 30°C. At higher temperatures, this net reduced the temperature by 1.2 to 2.7°C. The minimum temperature was 24°C. The outside temperature was then 24.8°C. 37.7°C was the maximum observed temperature corresponding to an outside temperature of 39.2°C. When the outside temperature was 30°C, the inside temperature was 28.3°C.

Comparing the shading effects of these four shade nets on temperature, the highest temperature was always under the B50 shade net and the lowest was under the G75 shade net. There was not much difference in temperature under B75 and G50 shade nets. The temperature was reduced with increased intensity of shading. The temperature under the black nets was higher than that under the green nets.

4.1.1 Relationships between the Inside and Outside Temperatures

The outside temperatures were plotted against the temperatures in the open space to obtain the nature of relationship between them. The relationship was found to be linear and the slope of the line varied at outside temperature of

34°C. Regression analysis was done to develop relationships between the temperatures in the open space and under shades. Considering the inside temperature as the dependant variable and the outside temperature as the independent variable, the equations developed are,

For G50 shade net when the outside temperature is less than or equal to 34°C, the equation was

$$y = 0.812\,x + 4.61 \text{ (correlation coefficient } r = 0.98)$$

For G50 shade net, when the outside temperature is more than 34°C,

$$y = 0.956\,x - 0.36 \text{ (correlation coefficient } r = 0.96)$$

For B50 shade net, when the outside temperature is less than or equal to 34°C, the equation was

$$y = 0.786\,x + 6.09 \text{ (correlation coefficient } r = 0.98)$$

For B50 shade net, when the outside temperature is more than 34°C,

$$y = 0.92\,x + 1.67 \text{ (correlation coefficient } r = 0.96)$$

For G75 shade net, when the outside temperature is less than or equal to 34°C, the equation was

$$y = 0.805\,x + 4.25 \text{ (correlation coefficient } r = 0.97)$$

For G75 shade net, when the outside temperature is more than 34°C, the equation was

$$y = 0.981\,x - 2.01 \text{ (correlation coefficient } r = 0.95)$$

For B75 shade net, when the outside temperature is less than or equal to 34°C, the equation was

$$y = 0.818\,x + 4.28 \text{ (correlation coefficient } r = 0.98)$$

For B75 shade net, when the outside temperature is more than 34°C, the equation was

$$y = 0.955\,x + 0.45 \text{ (correlation coefficient } r = 0.96)$$

These relationships were obtained, by analyzing the first nine weeks data. These equations will be useful in predicting the temperature under these shade nets based on outside temperatures..

These equations were used to predict the tenth week's data. The observed and predicted values of temperatures under the four shade nets for the X week of study are given in Table 6. The predicted values were plotted against the observed values (Figs.4 to 7). In all the four cases, straight lines were obtained with 1:1 slope indicating perfect correlation between the predicted and observed values.

4.2 RELATIVE HUMIDITY

The weekly average values of daily outside relative humidity at one hour interval from 7.30 a.m. to 5.30 p.m. during the ten weeks of study are given in Table 7. The corresponding RH values under G50, B50, G75 and B75 shade nets are given in Tables 8, 9, 10 and 11 respectively.

These RH values were plotted against time (Figs.8 and 9) to obtain the pattern of variation under each case. These plots clearly indicate that the patterns of variation inside and outside the shade nets are always the same.

Always the RH under the G50 shade net was higher than that in the open space. The maximum outside RH observed was 91.67 per cent. The corresponding RH under this net was 96.83 per cent. When the RH in the open space was 90 per cent the RH under the net was 91 per cent. Corresponding to the 80.5 per cent RH in the open space, RH under the net was 82 per cent. When the outside RH was 70 per cent, the net increased the RH to 75 per cent. The RH under the G50 shade net were 65.4 per cent and 55 per cent, when the RH in the

Table 6. Observed and predicted weekly average daily temperatures for the X week under the four shade nets.

Temperature (°C)								
	G50		B50		G75		B75	
Time (h)	Obs. Values	Pred. Values	Obs. Values	Pred. Values	Obs. Values	Pred. Values	Obs. Values	Pred. Values
7.30	27.00	26.94	27.80	27.71	26.30	26.39	26.80	26.78
8.30	29.70	29.95	30.30	30.61	29.50	29.37	29.80	29.80
9.30	32.00	32.24	32.90	33.04	31.43	31.44	32.10	32.12
10.30	33.33	33.30	34.30	34.05	32.70	32.52	33.00	33.17
11.30	34.50	34.73	35.70	35.43	34.00	33.99	34.60	34.60
12.30	34.40	34.63	35.40	35.34	33.90	33.89	34.40	34.51
1.30	33.40	33.49	34.20	34.24	32.90	32.72	33.30	33.36
2.30	34.10	34.16	34.90	34.88	33.60	33.40	33.90	34.03
3.30	32.50	32.72	33.50	33.50	31.80	31.93	32.70	32.60
4.30	31.60	31.57	32.30	32.19	30.60	30.98	31.40	31.44
5.30	30.70	30.68	31.30	31.32	30.00	30.10	30.50	30.54

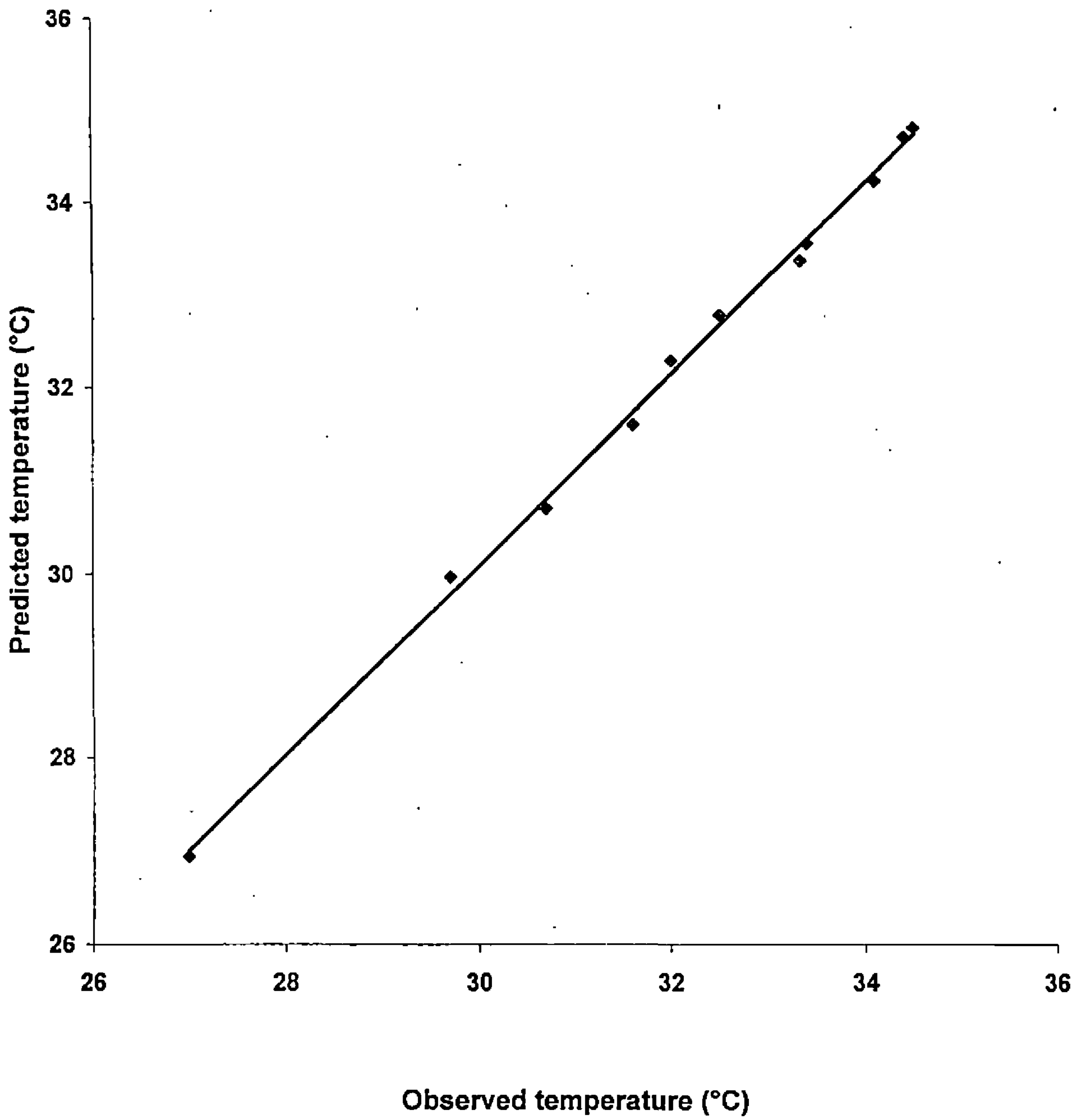

Fig.4 Observed vs predicted temperature under the G50 shade net

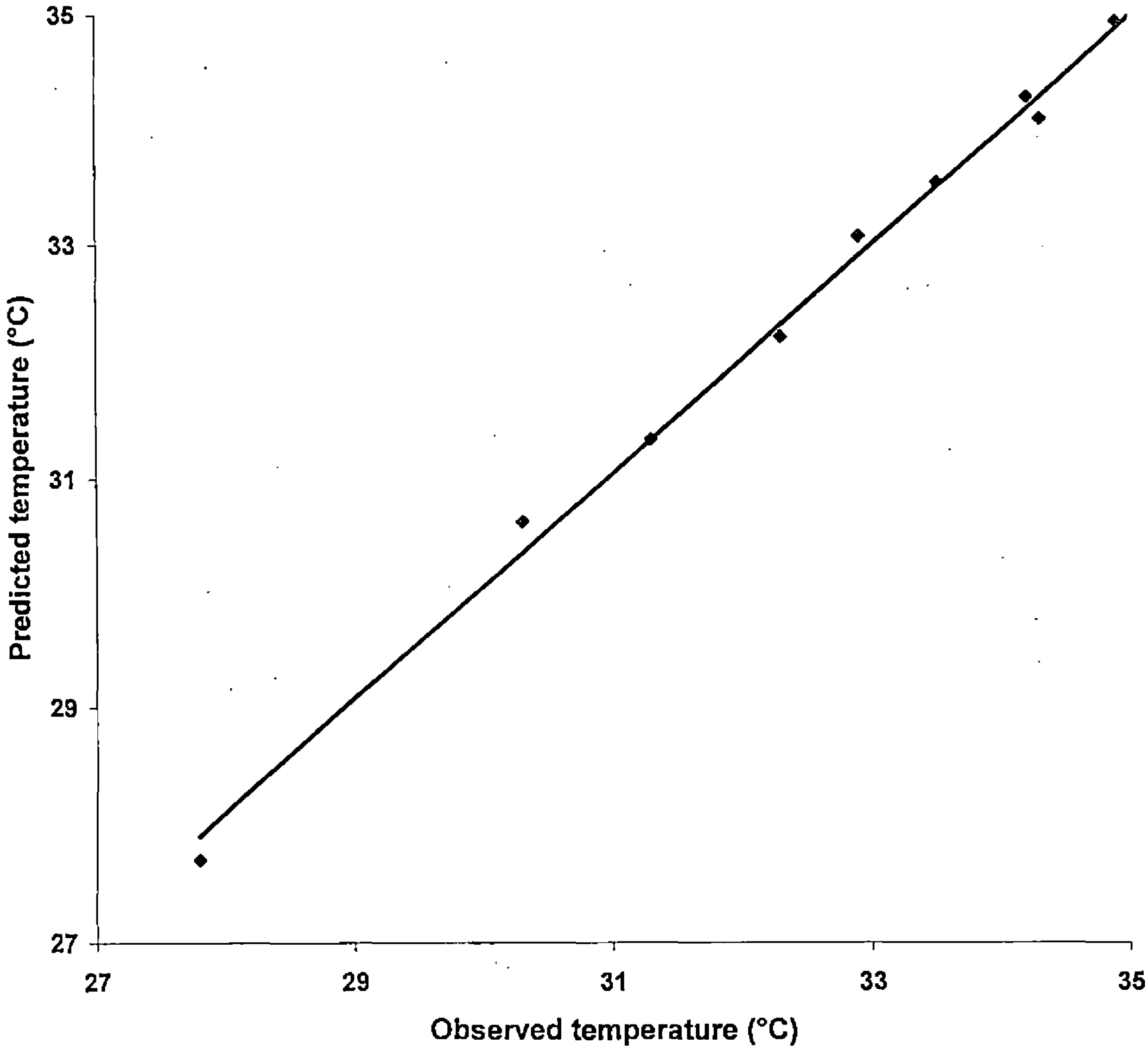

Fig.5 Observed vs predicted temperature under the B50 shade net

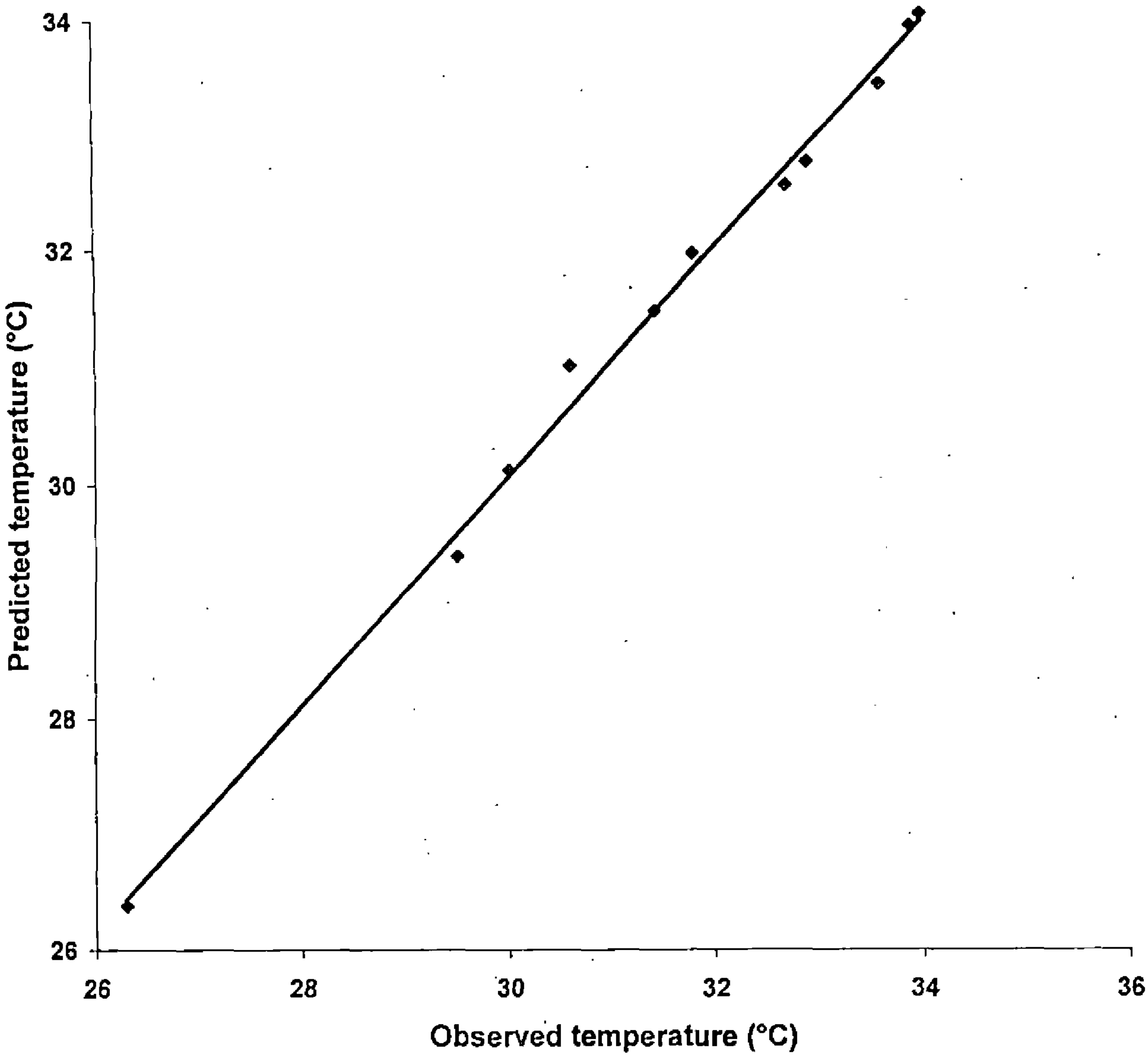

Fig.6 Observed vs predicted temperature under the G75 shade net

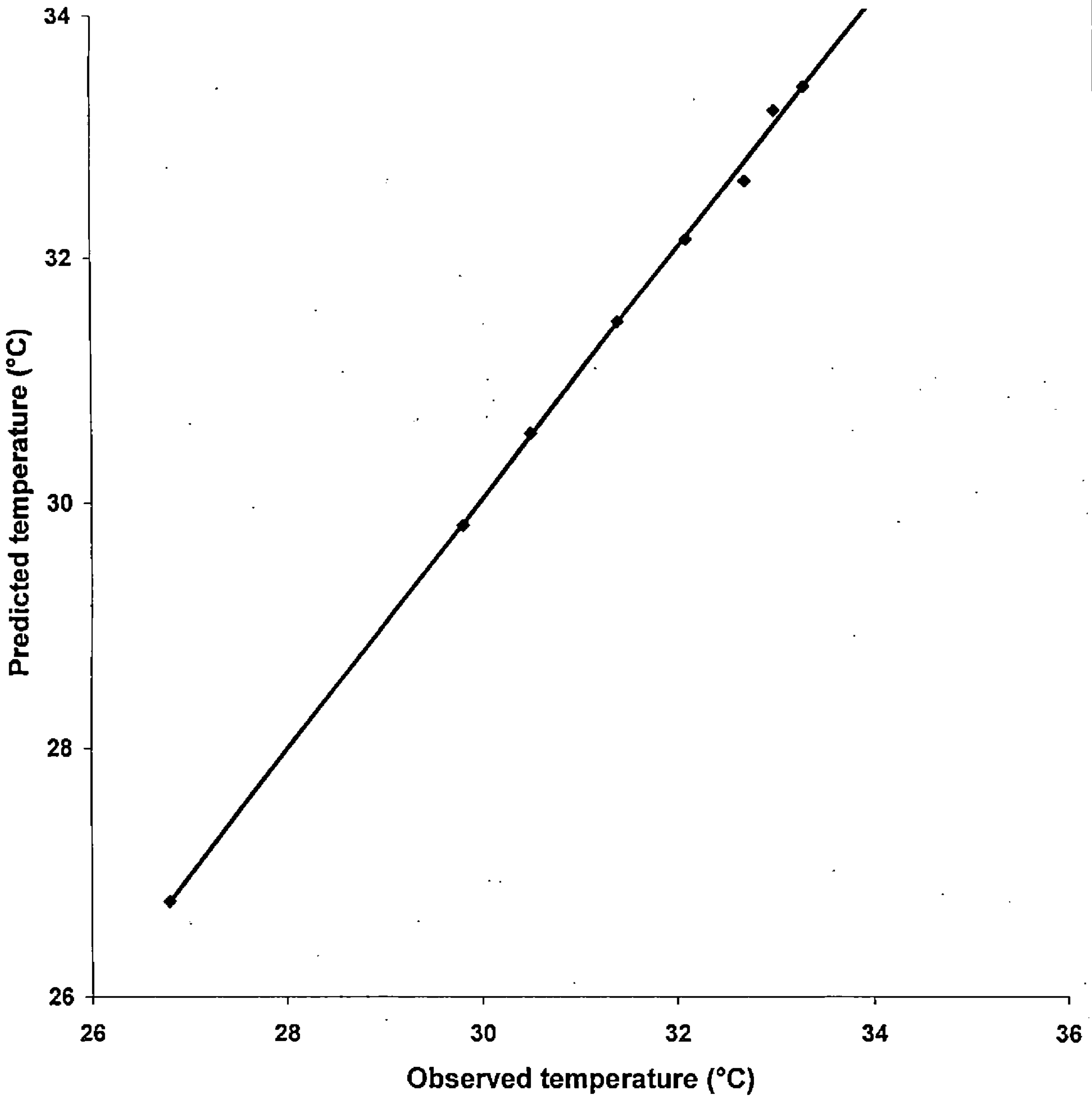

Fig.7 Observed vs predicted temperature under the B75 shade net

Table 7. Weekly average daily outside RH from 7.30 am to 5.30 pm during the 10 weeks from 01.03.1995 to 09.05.1995.

	Relative humidity (%)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	91.67	82.44	64.17	54.50	47.33	50.33	48.50	48.33	54.17	62.25	66.75
II	90.00	75.50	62.25	56.25	48.50	45.25	45.75	51.00	50.00	55.00	61.00
III	88.00	72.33	59.00	58.00	50.00	49.00	51.50	50.00	53.50	56.00	58.00
IV	85.50	71.63	63.67	57.63	49.50	55.75	50.33	49.50	52.50	54.00	62.00
V	79.00	71.50	61.60	52.50	48.10	46.20	50.17	48.75	52.50	59.25	61.00
VI	80.50	74.25	64.50	57.83	50.75	52.00	53.25	55.50	58.50	58.00	61.00
VII	82.00	69.00	58.00	53.50	52.00	65.00	57.50	59.00	57.00	65.00	70.00
VIII	84.25	75.75	64.75	61.50	61.00	62.13	58.00	61.88	62.00	65.67	68.25
IX	89.00	81.50	68.33	64.68	60.50	56.83	60.77	61.33	69.75	65.33	72.00
X	86.00	79.00	71.00	67.00	62.00	64.00	61.00	60.00	62.50	66.00	78.00

Table 8. Weekly average daily RH from 7.30 am to 5.30 pm under the G50 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.

	Relative humidity (%)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	96.83	84.17	72.17	62.50	53.33	56.33	56.50	54.17	60.17	66.25	71.50
II	91.00	78.00	70.25	60.75	55.00	51.00	50.50	54.00	56.25	62.00	66.00
III	95.00	77.83	66.50	61.00	54.00	54.00	55.00	55.50	58.00	62.00	66.00
IV	91.00	77.88	69.00	62.00	54.33	62.00	57.50	56.50	58.50	60.25	67.00
V	80.67	75.50	66.50	57.23	52.60	52.10	55.50	53.50	57.50	62.38	67.00
VI	82.00	77.25	68.50	62.00	55.00	57.50	57.75	61.33	63.00	64.00	67.00
VII	86.00	77.50	65.00	60.00	61.00	71.00	68.00	69.00	64.00	72.00	75.00
VIII	88.25	81.25	70.63	66.50	66.75	69.25	66.83	69.00	68.67	73.67	77.00
IX	96.75	88.00	73.00	70.00	66.67	63.00	69.33	68.83	78.25	72.67	78.83
X	90.50	84.00	76.50	72.50	67.20	69.60	65.90	65.40	67.90	71.30	83.30

Table 9. Weekly average daily RH from 7.30 am to 5.30 pm under the B50 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.

	Relative humidity (%)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	90.33	82.67	69.00	59.17	51.17	54.50	54.17	51.50	57.17	64.75	70.25
II	87.00	75.00	64.75	58.25	57.75	49.00	48.00	53.00	54.25	59.00	64.00
III	92.50	75.33	63.25	59.50	52.00	51.50	53.00	52.67	54.50	60.00	63.00
IV	86.50	75.00	66.00	60.50	52.17	59.00	53.17	53.17	56.17	56.50	66.00
V	79.67	73.63	64.00	55.38	50.50	49.10	53.33	51.38	55.75	62.25	64.75
VI	78.83	75.75	66.00	60.17	52.50	53.00	55.75	57.67	60.50	60.00	64.75
VII	85.00	73.00	60.00	57.00	56.50	68.00	62.00	64.00	62.25	71.00	73.00
VIII	83.88	78.00	67.50	64.38	63.38	66.00	62.33	65.00	65.33	70.67	75.00
IX	93.75	83.25	71.00	67.17	63.17	59.67	64.67	64.33	74.50	70.17	77.17
X	87.80	81.50	73.50	70.00	64.60	67.30	63.70	63.00	65.70	69.00	80.50

Table 10. Weekly average daily RH from 7.30 am to 5.30 pm under the G75 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.

	Relative humidity (%)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	100.00	93.67	80.83	70.00	60.33	63.83	63.67	61.67	67.00	73.50	80.25
II	99.00	85.00	77.75	68.50	63.50	56.75	55.75	64.00	65.00	68.00	74.50
III	100.00	86.17	71.50	70.00	63.00	62.00	62.50	62.00	67.50	70.00	77.50
IV	96.25	86.38	76.33	70.38	63.33	68.25	62.00	62.17	67.17	68.75	73.00
V	89.00	82.90	73.70	65.00	60.20	59.80	64.67	62.00	65.50	72.13	73.50
VI	95.00	88.75	79.25	71.17	63.50	65.00	66.50	68.67	72.75	72.00	73.50
VII	95.00	86.00	74.00	70.00	71.50	82.50	72.00	75.00	77.00	81.00	86.00
VIII	93.38	92.63	81.00	75.88	76.00	77.88	75.00	78.50	77.83	85.67	86.25
IX	100.00	95.50	82.33	80.35	75.67	71.67	77.50	76.67	84.00	81.83	86.33
X	99.10	91.30	85.00	80.65	77.00	79.10	76.00	73.70	77.40	80.50	92.50

Table 11. **Weekly average daily RH from 7.30 am to 5.30 pm under the B75 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.**

	Relative humidity (%)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	99.13	92.69	79.64	68.64	58.81	62.37	62.21	60.17	65.59	72.19	79.05
II	98.11	83.88	76.51	67.11	62.03	55.17	54.16	62.54	63.56	66.61	73.21
III	99.13	85.07	70.16	68.64	61.52	60.51	61.02	60.51	66.10	68.64	76.26
IV	95.31	85.28	75.07	69.02	61.86	66.86	60.51	60.68	65.76	67.37	71.69
V	87.00	81.50	71.00	66.25	58.33	58.33	63.00	60.83	63.50	74.00	75.00
VI	89.83	87.75	78.25	68.67	61.50	64.00	65.00	67.50	72.00	71.00	75.00
VII	90.00	85.00	73.50	67.00	65.00	81.00	71.00	72.00	74.00	80.00	86.00
VIII	96.50	91.50	78.75	74.13	74.25	76.63	75.33	77.75	76.33	85.50	87.13
IX	100.00	95.00	79.67	78.67	73.00	68.67	75.17	76.00	85.00	81.00	88.50
X	98.10	90.90	83.90	79.60	75.80	77.30	74.10	72.80	75.91	79.10	91.50

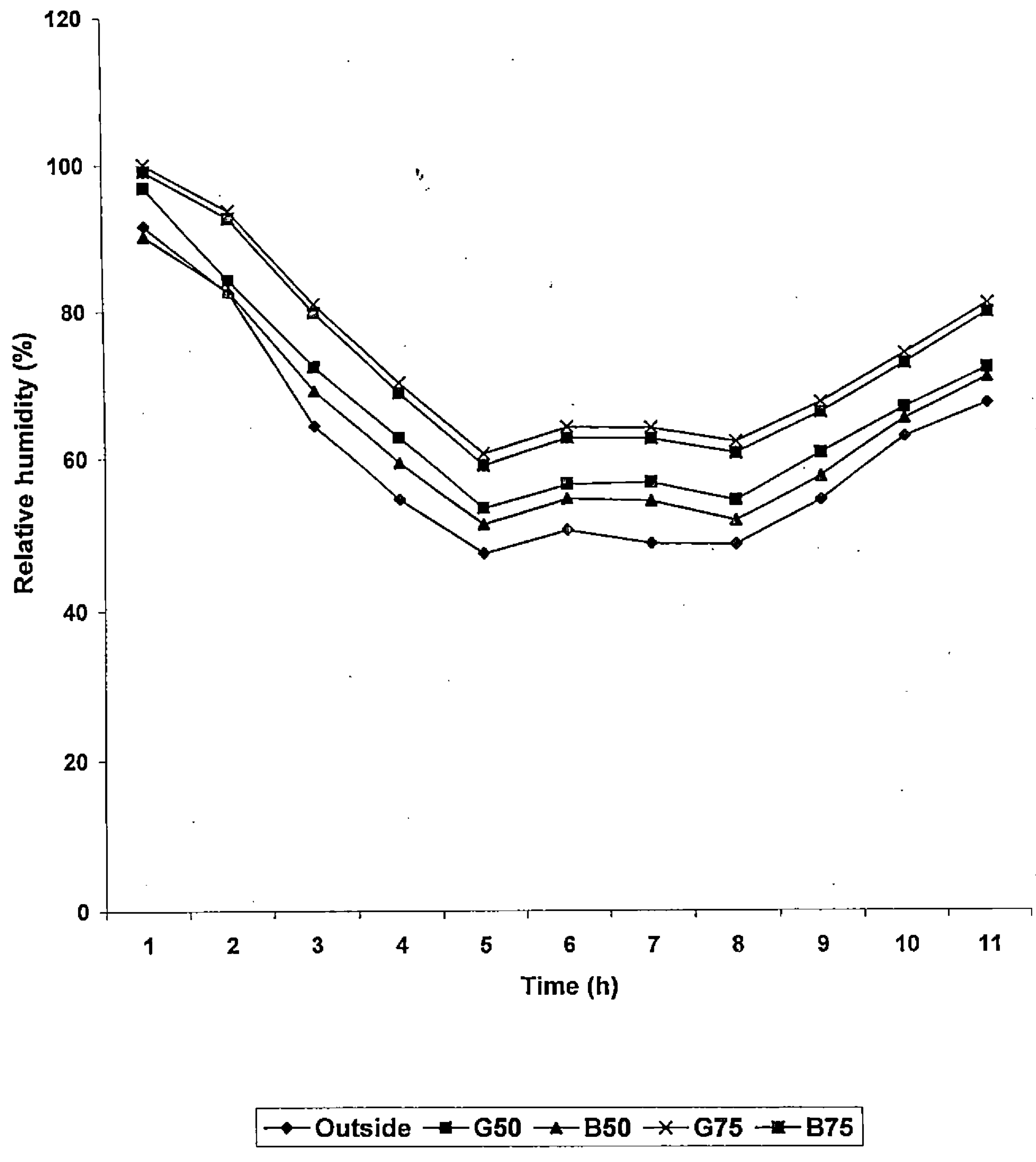

Fig.8 Weekly average daily variation of inside and outside RH during the I week (1.3.95 to 7.3.95)

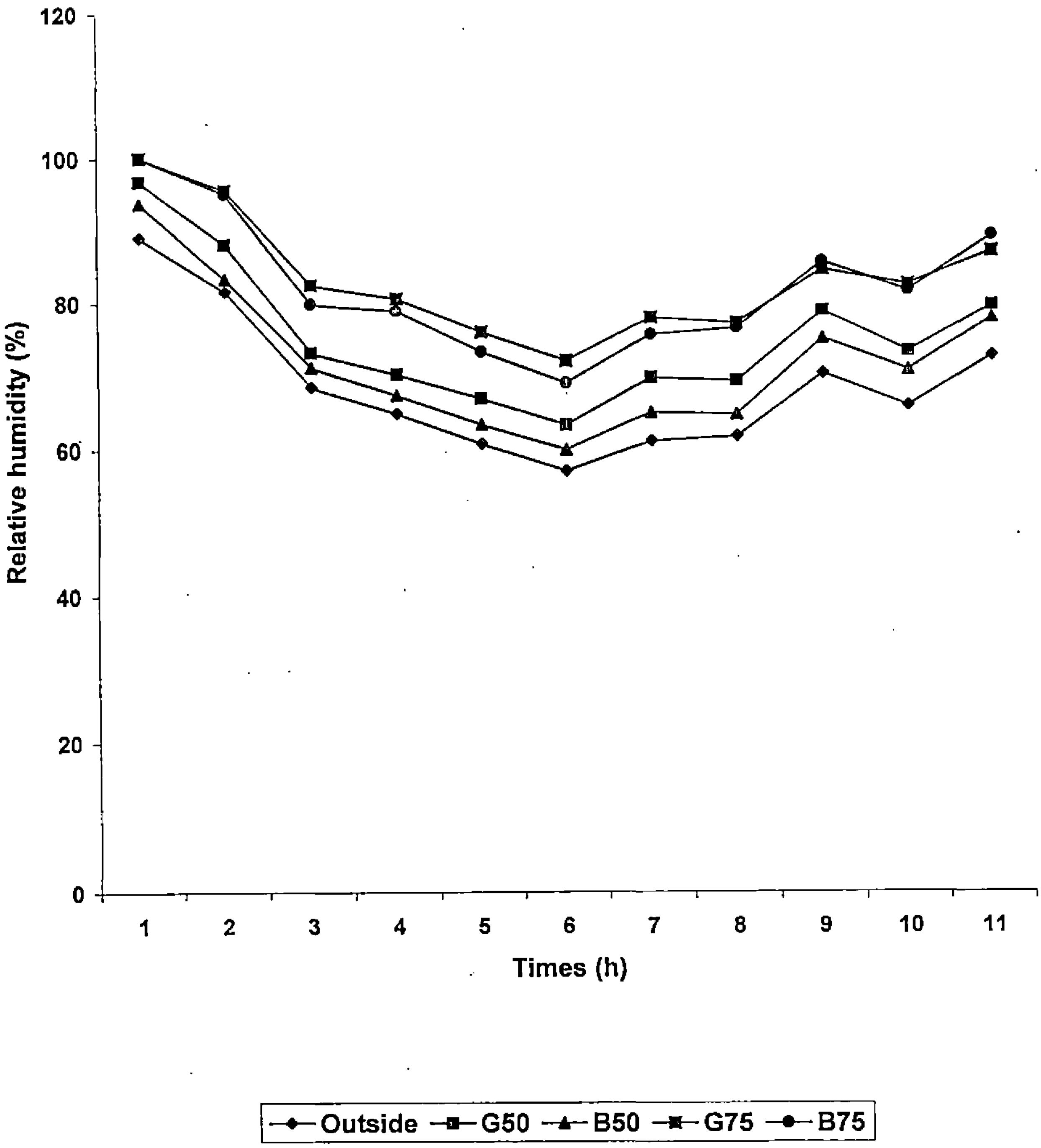

Fig.9 Weekly average daily variation of inside and outside RH during the IX week (26.4.95 to 2.5.95)

open space were 60 per cent and 50 per cent respectively. The minimum outside RH observed was 45.25 per cent. The RH under the net was then 51 per cent.

The B50 shade net also caused an increase in the relative humidity. The maximum RH obtained was 92.5 per cent corresponding to an RH of 88 per cent in the open space. Corresponding to an outside RH of 90 per cent, 80.5 per cent, 70 per cent, 60 per cent and 50 per cent, the RH under this shade net were 87 per cent, 78.83 per cent, 73 per cent, 63 per cent and 52 per cent respectively. The minimum RH observed was 48 per cent corresponding to 48.75 per cent outside RH.

Under the G75 shade net, the RH was very high at 7.30 a.m. on most of the days. On some days it was even 100 per cent. The RH was always higher than 55 per cent under this net, whereas it went down to 45 per cent at sometimes in the open space. At noon time, the RH under this shade net was around 60 per cent. The relative humidity were 99 per cent, 95 per cent, 86 per cent, 73.7 per cent and 62.5 per cent corresponding to the outside relative humidity of 90 per cent, 80.5 per cent, 70 per cent, 60 per cent and 50 per cent. The lowest RH observed under this shading condition was 55.75 per cent.

Under the B75 shade net also the RH was very high at 7.30 a.m. but less than that under G75 shade net. The minimum observed RH was 54.16 per cent. The relative humidity under this shading condition was 98.11 per cent, 89.83 per cent, 86 per cent, 72.8 per cent and 61 per cent corresponding to 90 per cent, 80.5 per cent, 70 per cent, 60 per cent and 50 per cent outside RH respectively. Even at noontime, the RH was comparatively much higher.

Comparing the relative humidity under the four shade nets, the highest RH was always under G75 shade net. The lowest RH was always under B50 shade net. The RH under B75 and G50 shade nets were always in between of which higher RH was under B75 shade net. The relative humidity increased with the increased shading intensities. Comparing the green and black shade nets, higher RH was under green shade nets.

4.2.1 Relationships between the Inside and Outside RH

A linear relation was observed when the inside RH values were plotted against those outside. Regression analysis was done on nine week's data to obtain the relationships between the inside and outside RH. The dependent variable considered was the outside RH and inside RH, the independent variable. The resulting equations are,

For G50 shade net,

Y = 0.968 x + 7.69 (correlation coefficient, r = 0.99)

For B50 shade net,

Y = 0.947 x + 6.26 (correlation coefficient, r = 0.99)

For G75 shade net,

Y = 0.961 x + 16.32 (correlation coefficient, r = 0.98)

For B50 shade net,

Y = 0.981 x + 13.79 (correlation coefficient, r = 0.98)

These equations were used to predict the RH during the tenth week. The observed and predicted values under the four shade nets for the X week of study are given in Table 12. The predicted values were plotted against the observed values (Figs 10 to 13). The straight lines with 1:1 slopes indicate perfect correlation between predicted and observed data.

Table 12. Observed and predicted weekly average daily RH for the X week under the four shade nets.

Relative humidity (%)								
	G50		B50		G75		B75	
Time (h)	Obs. Values	Pred. Values	Obs. Values	Pred. Values	Obs. Values	Pred. Values	Obs. Values	Pred. Values
7.30	90.50	90.96	87.80	87.70	99.10	98.88	98.10	98.16
8.30	84.00	84.18	81.50	81.07	91.30	92.16	90.90	91.29
9.30	76.50	76.44	73.50	73.49	85.00	84.48	83.90	83.44
10.30	72.50	72.56	70.00	69.71	80.65	80.64	79.60	79.52
11.30	67.20	67.72	64.60	64.97	77.00	75.84	75.80	74.61
12.30	69.60	69.66	67.30	66.87	79.10	77.76	77.30	76.58
1.30	65.90	66.76	63.70	64.02	76.00	74.88	74.10	73.63
2.30	65.40	65.79	63.00	63.08	73.70	73.92	72.80	72.65
3.30	67.90	68.21	65.70	65.45	77.40	76.32	75.91	75.10
4.30	71.30	71.60	69.00	68.76	80.50	79.68	79.10	78.54
5.30	83.30	83.21	80.50	80.12	92.50	91.20	91.50	90.31

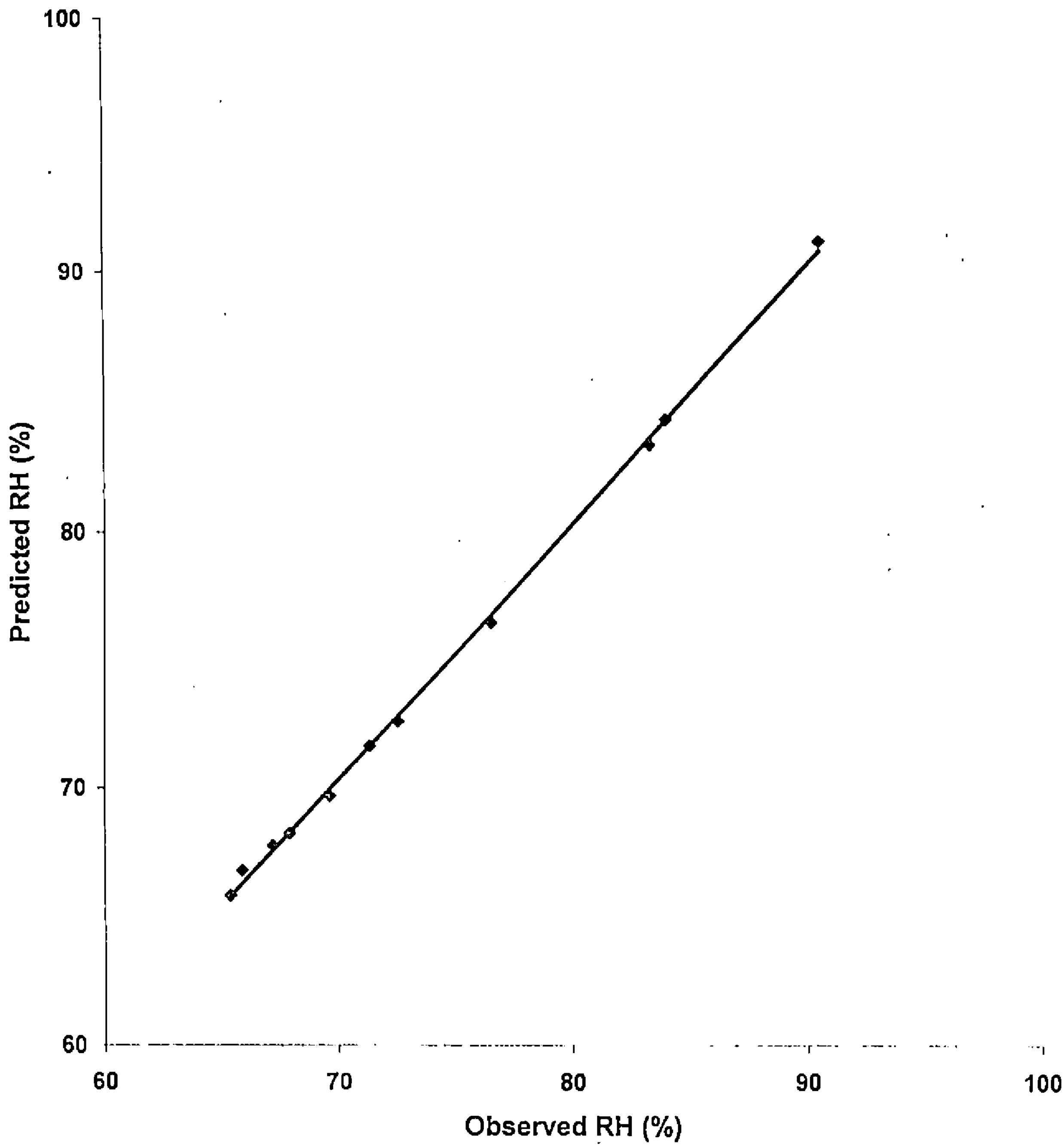

Fig.10 Observed vs predicted RH under the G50 shade net

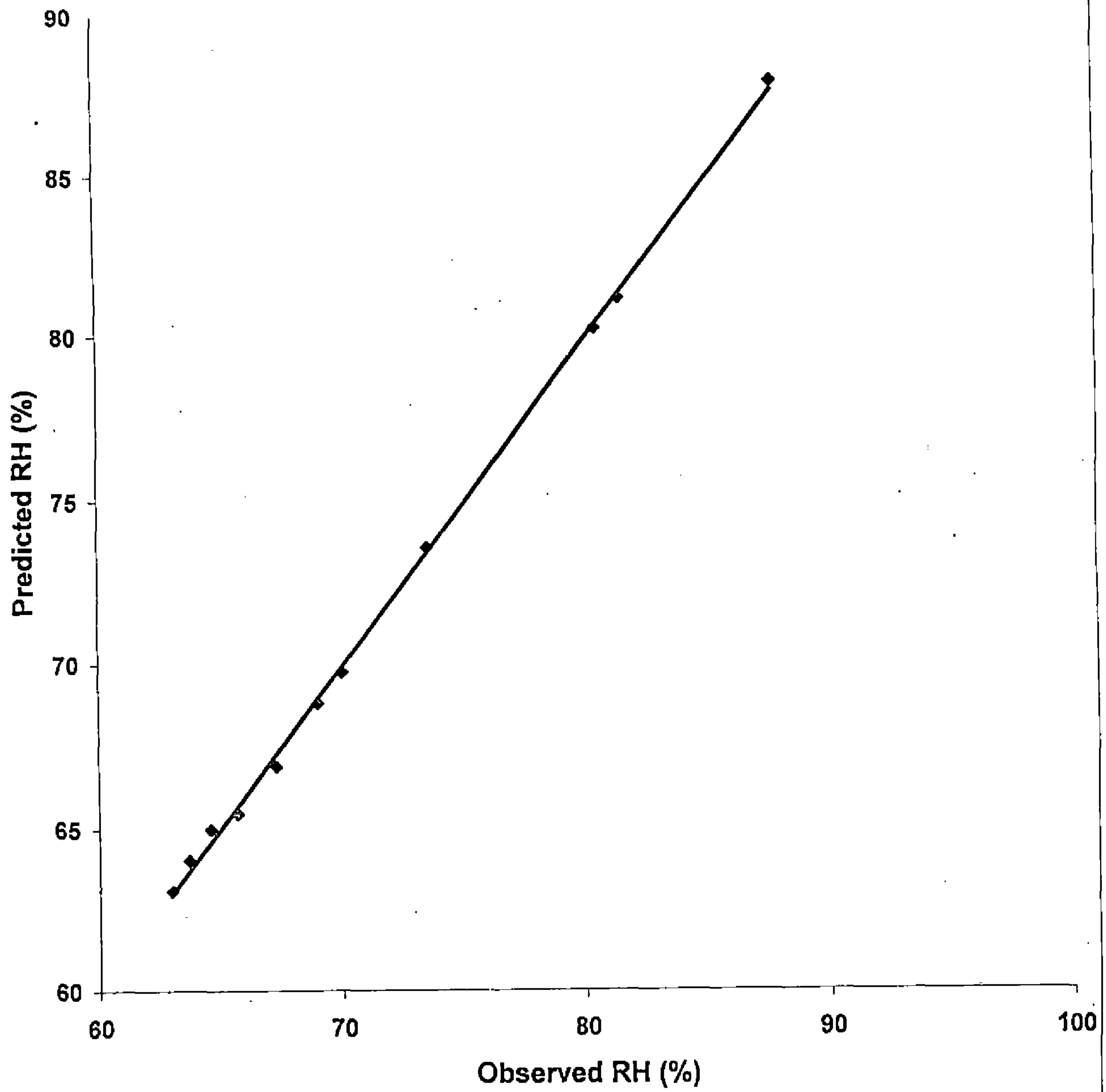

Fig.11 Observed vs predicted RH under the B50 shade net

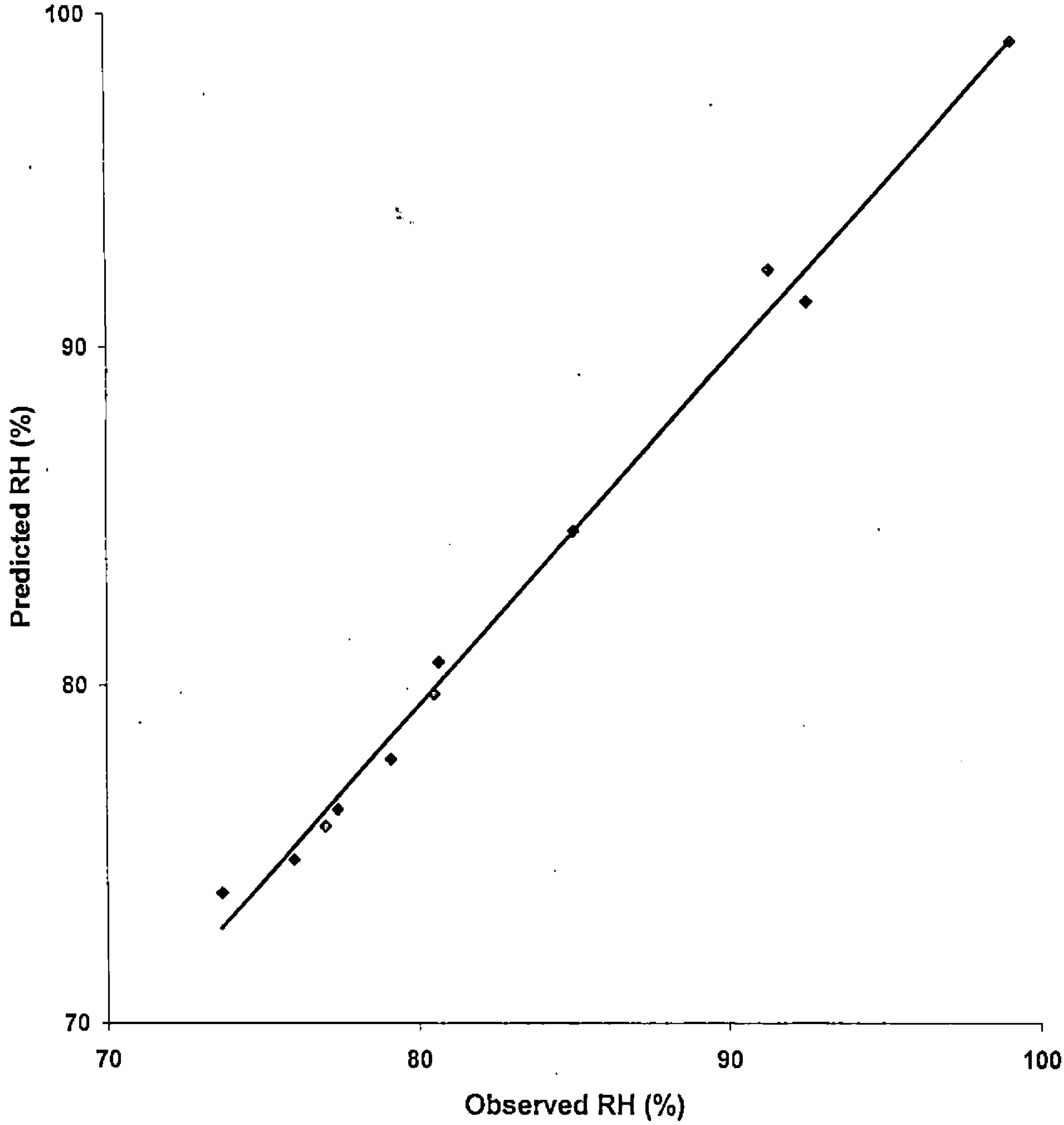

Fig.12 Observed vs predicted RH under the G75 shade net

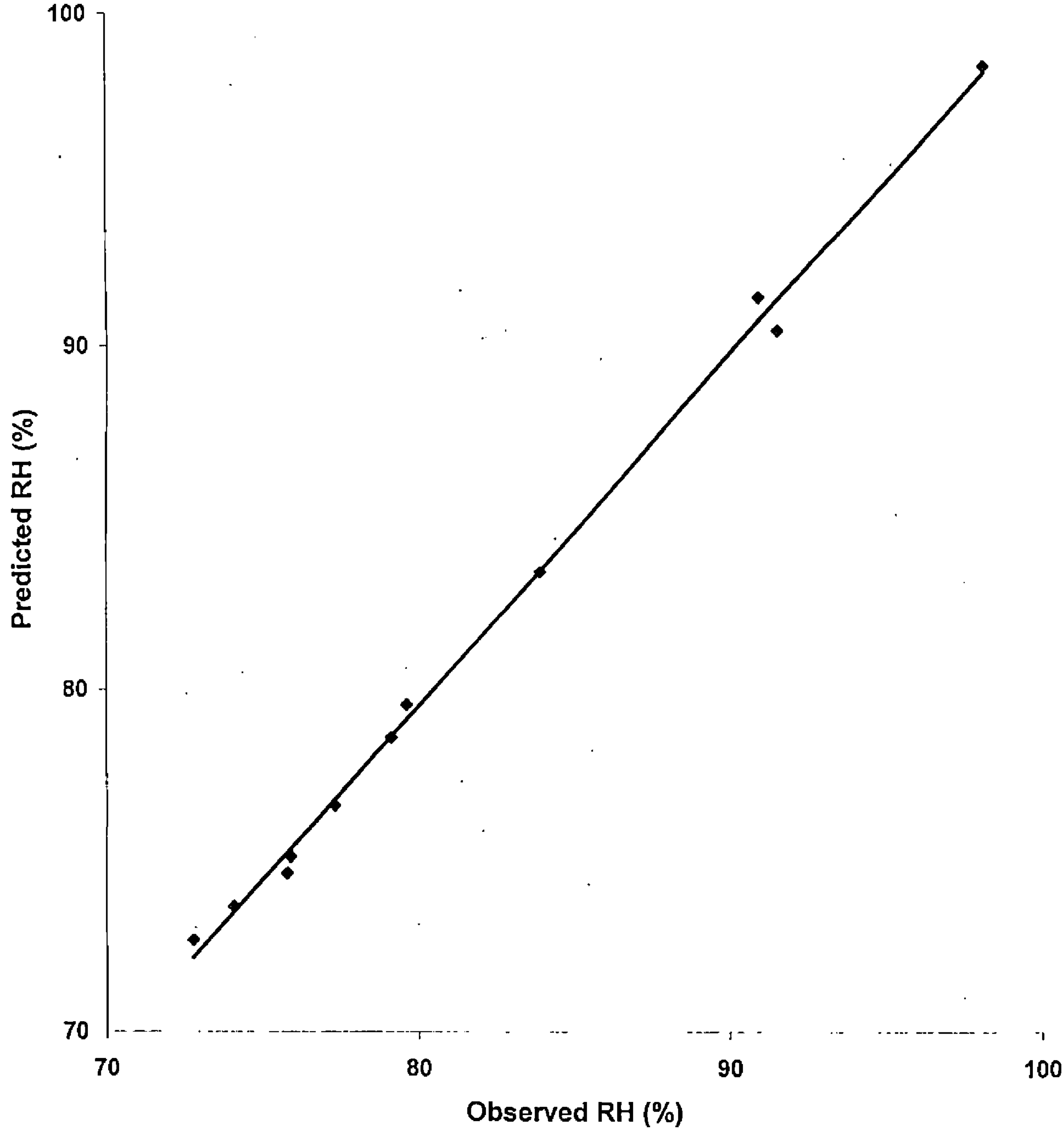

Fig.13 Observed vs predicted RH under the B75 shade net

4.3 SOLAR RADIATION INTENSITY

The solar radiation intensities under the different shade nets were much lower than that in the open space. Table 13 gives the weekly average daily solar radiation intensities in the open space taken at one hour interval from 7.30 a.m. to 5.30 p.m. during the ten weeks of study. Tables 14, 15, 16 and 17 gives the corresponding readings under the G50, B50, G75 and B75 shade nets respectively. These values were plotted against time (Fig 14 and 15) and give a clear idea about the variation of solar radiation intensity under the different shades.

When the outside solar radiation intensity was less than 50 W/m^2, it was always less than 20 W/m^2 under the G50 shade net. The intensity of solar radiation under this net was 19 W/m^2 when the outside intensity was 51 W/m^2. When the intensity in the open space was around 100 W/m^2, it was around 25 W/m^2 under the G50 shade net. When the outside intensity was increased to around 200 W/m^2, the intensity under this net was increased only to around 50 W/m^2. Corresponding to outside solar radiation intensities of 298, 411, 600, 715 and 870 W/m^2, the inside intensities were 125, 165, 223 and 418 W/m^2 respectively. The maximum intensity observed under this shade net was 418 W/m^2. It was 48 per cent of the maximum outside solar radiation intensity. The average intensity of solar radiation at noon under this net was 292 W/m^2 whereas it was 655 W/m^2 in the open space. Under this net, the average intensity was 44.5 per cent of that in the outside.

Under the B50 shade net, the solar radiation intensity was always less than 10 W/m^2, when the outside solar radiation intensity was less than or equal to 50 W/m^2. The solar radiation intensity under the shade net was much lower than that in the open space. The minimum intensity observed was 1 W/m^2 and the maximum intensity was 184 W/m^2. The maximum intensity was 21 per cent of that in the open space. Even at the noon time, the average intensity was only 127 W/m^2 corresponding to 655 W/m^2 in the open space.

Table 13. **Weekly average daily outside solar radiation intensity from 7.30 am to 5.30 pm during the 10 weeks from 01.03.1995 to 09.05.1995.**

	Solar radiation intensity (W/m^2)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	38	79	375	587	729	750	715	611	457	215	33
II	47	59	429	411	644	600	733	478	274	176	87
III	65	114	503	628	776	692	773	616	378	116	29
IV	65	147	450	461	562	773	565	566	440	165	60
V	63	270	425	560	776	646	731	624	278	165	47
VI	135	274	428	696	912	870	675	613	282	192	51
VII	139	416	535	732	768	783	690	503	254	146	3
VIII	79	254	358	570	641	468	539	440	298	187	59
IX	58	365	384	539	786	790	296	539	212	86	49
X	89	266	511	620	673	722	681	467	126	94	70

Table 14. Weekly average daily intensity of solar radiation from 7.30 am to 5.30 pm under the G50 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.

	Solar radiation intensity (W/m^2)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	12	20	146	246	271	287	283	269	211	88	20
II	16	35	133	165	264	223	246	208	110	39	23
III	26	29	126	202	296	266	339	267	175	42	13
IV	21	44	186	156	210	255	266	210	159	43	23
V	25	60	137	201	338	272	280	230	112	37	14
VI	35	69	180	265	388	418	302	265	130	75	19
VII	12	97	187	262	225	379	253	148	103	42	2
VIII	18	64	149	231	278	214	233	189	125	39	16
IX	20	83	156	217	312	316	126	182	59	70	19
X	22	86	189	259	266	291	268	194	38	28	21

Table 15. Weekly average daily intensity of solar radiation from 7.30 am to 5.30 pm under the B50 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.

	Solar radiation intensity (W/m²)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	9	12	61	93	136	129	117	104	56	27	8
II	6	15	55	54	114	92	124	80	37	11	8
III	4	19	61	74	141	141	133	110	61	18	5
IV	9	20	70	78	75	86	104	107	43	17	10
V	17	25	55	99	141	122	129	90	68	17	6
VI	8	22	69	112	174	163	129	78	46	22	8
VII	5	19	79	138	158	184	84	93	42	18	1
VIII	8	18	64	104	116	108	81	82	38	17	7
IX	7	20	76	93	132	121	43	74	47	19	8
X	9	43	84	113	118	124	123	73	21	11	9

Table 16. Weekly average daily intensity of solar radiation from 7.30 am to 5.30 pm under the G75 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.

	Solar radiation intensity (W/m^2)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	11	14	122	189	232	241	176	115	100	52	13
II	13	43	105	107	231	194	212	96	36	34	12
III	11	23	94	173	209	168	214	126	70	38	9
IV	16	28	131	129	164	108	157	143	76	36	16
V	19	51	109	167	256	227	207	115	80	24	10
VI	26	55	130	211	308	280	148	83	64	44	13
VII	12	65	124	208	205	235	162	49	57	39	2
VIII	15	48	128	204	233	170	163	64	72	36	11
IX	16	87	128	171	275	241	92	115	51	45	13
X	19	64	131	167	191	202	178	124	25	18	14

Table 17. Weekly average daily intensity of solar radiation from 7.30 am to 5.30 pm under the B75 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.

	Solar radiation intensity (W/m^2)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	4	8	33	57	72	75	71	59	42	15	3
II	4	7	39	37	63	58	73	44	22	11	4
III	2	7	47	61	78	68	77	60	33	4	1
IV	3	7	41	42	54	77	54	54	40	9	3
V	3	8	27	56	110	57	82	61	31	13	4
VI	4	5	33	59	101	95	94	57	28	18	6
VII	2	9	16	59	78	94	72	37	15	11	1
VIII	3	9	22	47	73	64	52	35	17	10	4
IX	4	11	25	47	68	85	34	41	25	11	5
X	4	21	46	65	67	73	71	47	9	4	2

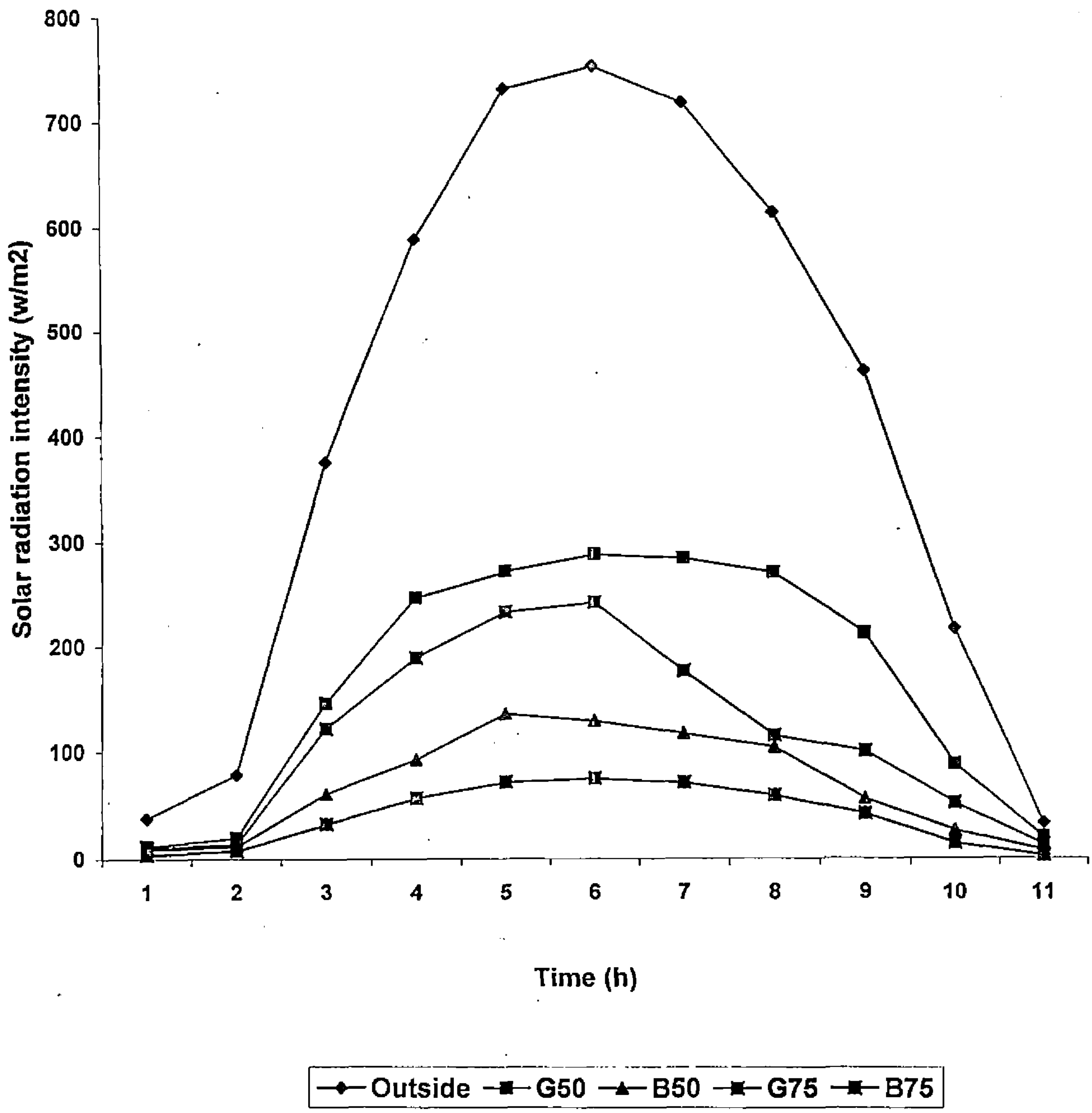

Fig.14 Weekly average daily variation of inside and outside solar radiation intensities during the I week (1.3.95 to 7.3.95)

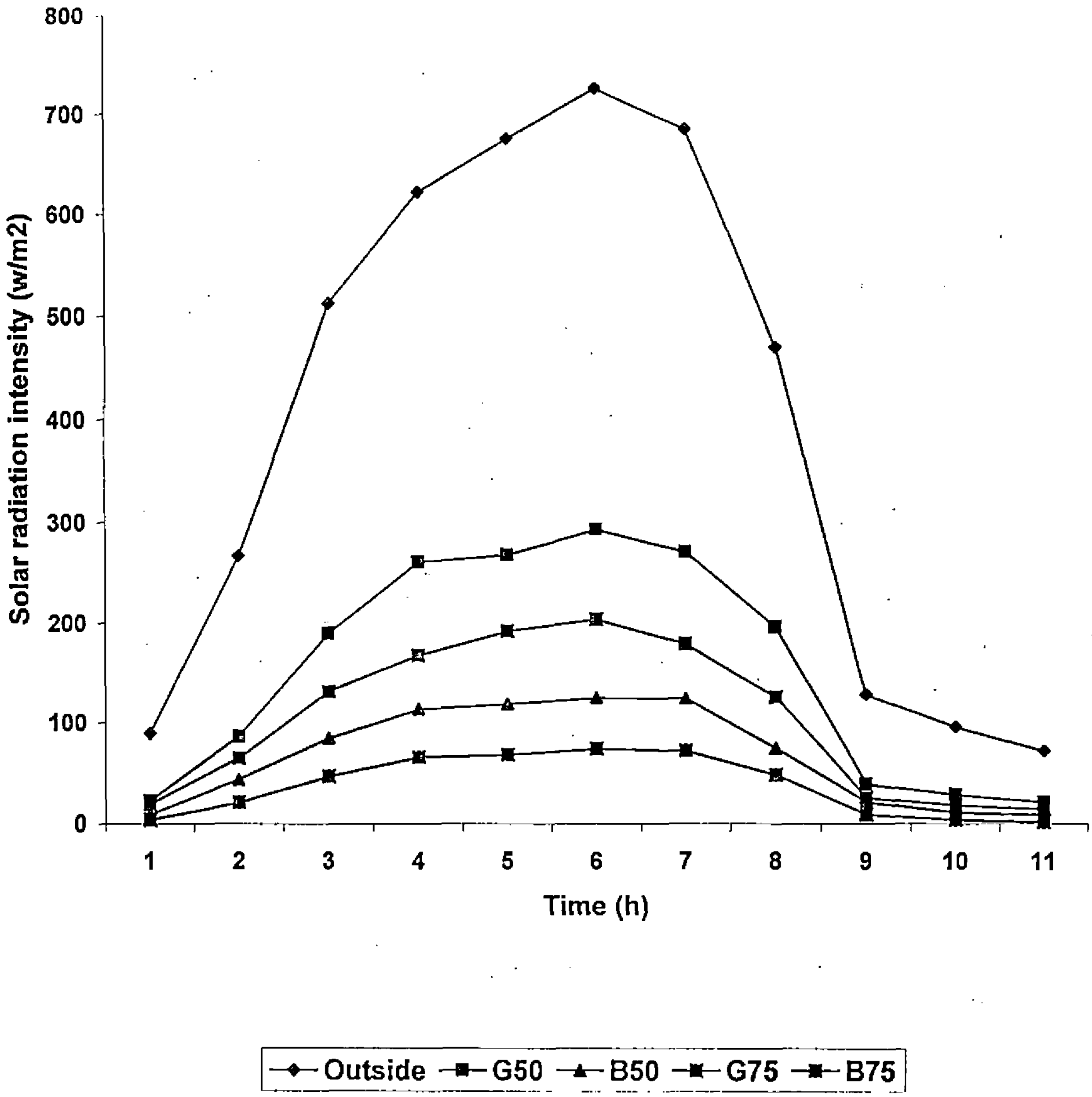

Fig.15 Weekly average daily variation of inside and outside solar radiation intensities during the X week (3.5.95 to 9.5.95)

Under the G75 shade net, the maximum solar intensity was 308 W/m^2 and the minimum observed intensity was 2 W/m^2. The maximum intensity was 35 per cent of that in the open space. At noon, the average intensity was 198 W/m^2. By 3.30 p.m. itself, the intensity under this net was reduced to below 100 W/m^2, whereas it was mostly above 250 W/m^2 in the open space.

The solar radiation intensity was always lowest under the B75 shade net. Most of the time, it was less than 100 W/m^2. Even at noon time, it was only 75 W/m^2 on an average. At 7.30 a.m. and 5.30 p.m., the intensity under this shade net was even less than 5 W/m^2. The lowest observed intensity was 1 W/m^2 and the highest intensity observed was 110 W/m^2. It was 12.6 per cent of the maximum intensity in the open space.

The patterns of variation under all the shade nets were similar to that in the open space. All the shade nets lowered the solar radiation intensity. Comparing the shading effects of the four shade nets studied, the highest solar radiation intensity was observed under G50 shade net and the lowest was under B75 shade net. Always the intensities under the two green nets were higher than that under the black nets. The intensities under G50 and B50 nets were higher than that under G75 and B75 nets respectively.

4.3.1 Relationships between the Inside and Outside Solar Radiation Intensities

The solar radiation intensities under the shades were plotted against that in the open space and a linear relationship was observed and the slope of the line varied at outside solar radiation intensity equal to 500 W/m^2. By regression analysis, the relationships between the inside and outside solar radiation intensities were developed. The independent variable considered was the inside solar radiation intensity and the dependent variable was the outside solar radiation intensity.

The equations are,

For the G50 shade net, when the outside intensity was less than or equal to 500 W/m^2,

$y = 0.395x - 7.33$ (correlation coefficient, $r = 0.94$)

For the B50 shade net, when the outside intensity was more than 500 W/m^2,

$y = 0.482x - 60.01$ (correlation coefficient, $r = 0.84$)

For the B50 shade net, when the outside intensity was less than or equal to 500 W/m^2,

$y = 0.15x + 12.92$ (correlation coefficient, $r = 0.87$)

For the B50 shade net, when the outside intensity was less than 500 W/m^2,

$y = 0.225x - 37.48$ (correlation coefficient, $r = 0.81$)

For the G75 shade net, when the outside intensity was less than or equal to 500 W/m^2,

$y = 0.249x - 1.15$ (correlation coefficient, $r = 0.90$)

For the G75 shade net, when the outside intensity was more than 500 W/m^2,

$y = 0.373x - 65.74$ (correlation coefficient, $r = 0.72$)

For the B75 shade net, when the outside intensity was less than or equal to 500 W/m^2,

$y = 0.853x - 2.25$ (correlation coefficient, $r = 0.87$)

For the B75 shade net, when the outside intensity is more than 500 W/m^2,

$y = 0.15x - 34.39$ (correlation coefficient, $r = 0.85$)

These equations can be used for predicting the solar radiation intensities under the four shading conditions, based on intensity in the open space. The tenth week's data were predicted using these equations. And the values are given in Table 18. The predicted values were plotted against observed values for determining the accuracy of prediction (Figs.16 to 19). The straight lines with 1:1 slope indicate good correlation between observed and predicted values.

4.4 LIGHT INTENSITY

Weekly average daily values of outside light intensities at one hour interval from 7.30 a.m. to 5.30 p.m. for the ten weeks of study are given in Table 19. The corresponding intensities under G50, B50, G75 and B75 shade nets are given in Tables 20, 21, 22 and 23 respectively. These values were plotted against time for the comparative evaluation of the performance of the nets and are shown in Figs. 20 and 21.

There was much difference between the light intensities in the open space and that under the nets. The pattern of variation inside and outside the nets remains the same.

At 7.30 a.m., the average light intensity in the open space was 134 x 10^2 lux; whereas under the G50 shade net it was 43 x 10^2 lux. The corresponding light intensities under B50, G75 and B75 nets were 18 x 10^2, 33 x 10^2 and 22 x 102 lux respectively. At 8.30 a.m., the outside light intensity increased to about 320 x 10^3 lux. Then the average light intensities under the G50, B50, G75 and B75 nets were 98 x 10^2, 36 x 10^2, 8 x 10^2 and 18 x 10^2 lux respectively. By 9.30 a.m., the average light intensity in the open space was 750 x 10^2 lux. Then it was only around 277 x 10^2, 126 x 10^2, 199 x 10^2 and 67 x 10^2 lux under the G50, B50, G75 and B75 nets respectively. From 10.30 a.m. to 2.30 p.m., the light intensities in the open space, varied from 700 x 10^2 – 1200 x 10^2 lux, whereas the

Table 18. Observed and predicted weekly average daily solar radiation intensities for the X week under the four shade nets.

Solar radiation intensity (W/m^2)								
	G50		B50		G75		B75	
Time (h)	Obs. Values	Pred. Values	Obs. Values	Pred. Values	Obs. Values	Pred. Values	Obs. Values	Pred. Values
7.30	22	28	9	11	19	21	4	5
8.30	86	98	43	38	64	65	21	20
9.30	189	186	84	77	131	125	46	42
10.30	259	239	113	102	167	165	65	59
11.30	266	264	118	114	191	185	67	67
12.30	291	288	124	125	202	203	73	74
1.30	268	268	123	116	178	188	71	68
2.30	194	177	73	68	124	115	47	37
3.30	38	42	21	17	25	30	9	8
4.30	28	30	11	12	18	22	4	6
5.30	21	20	9	9	14	16	2	4

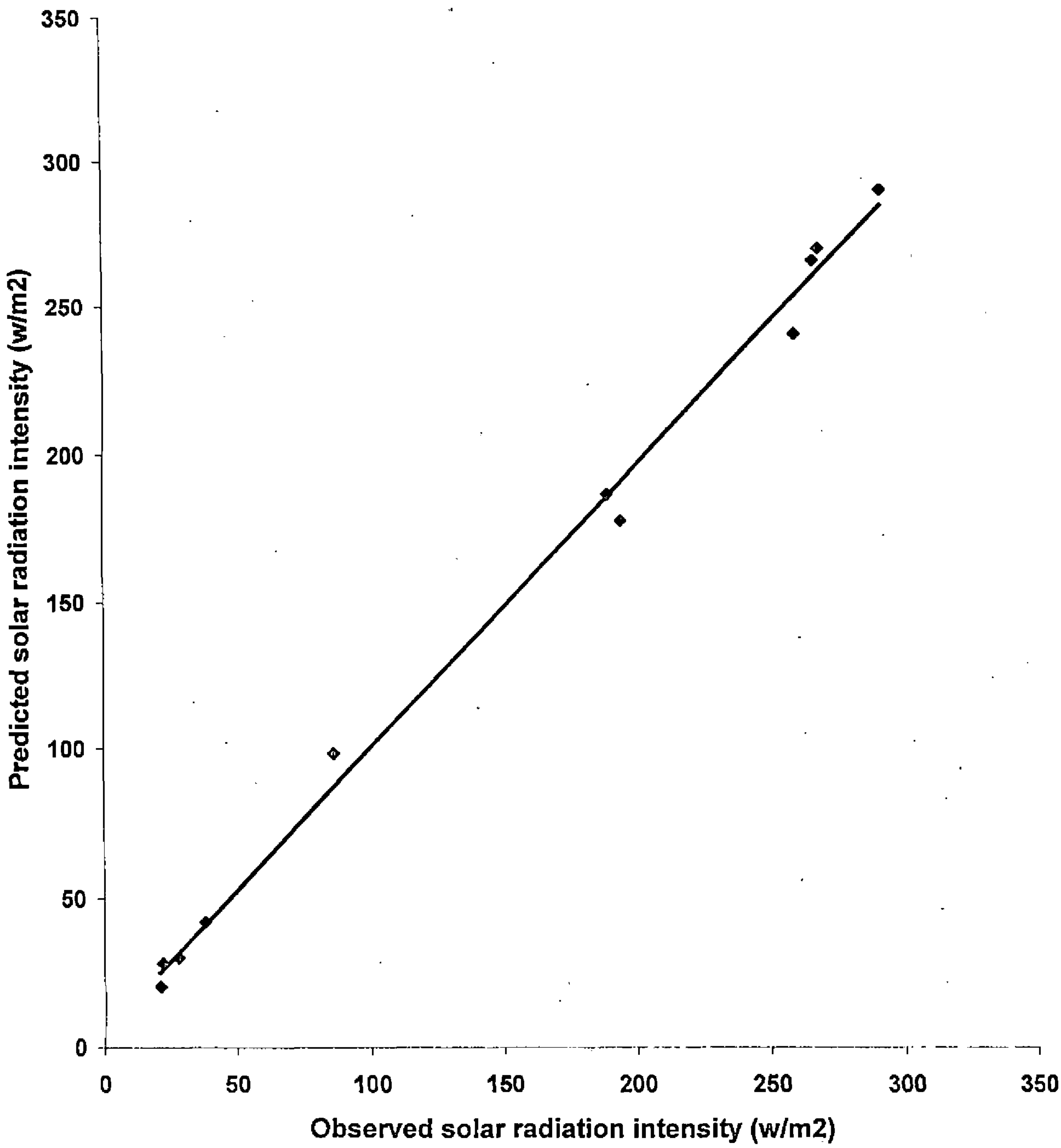

Fig.16 Observed vs predicted solar radiation intensity under the G50 shade net

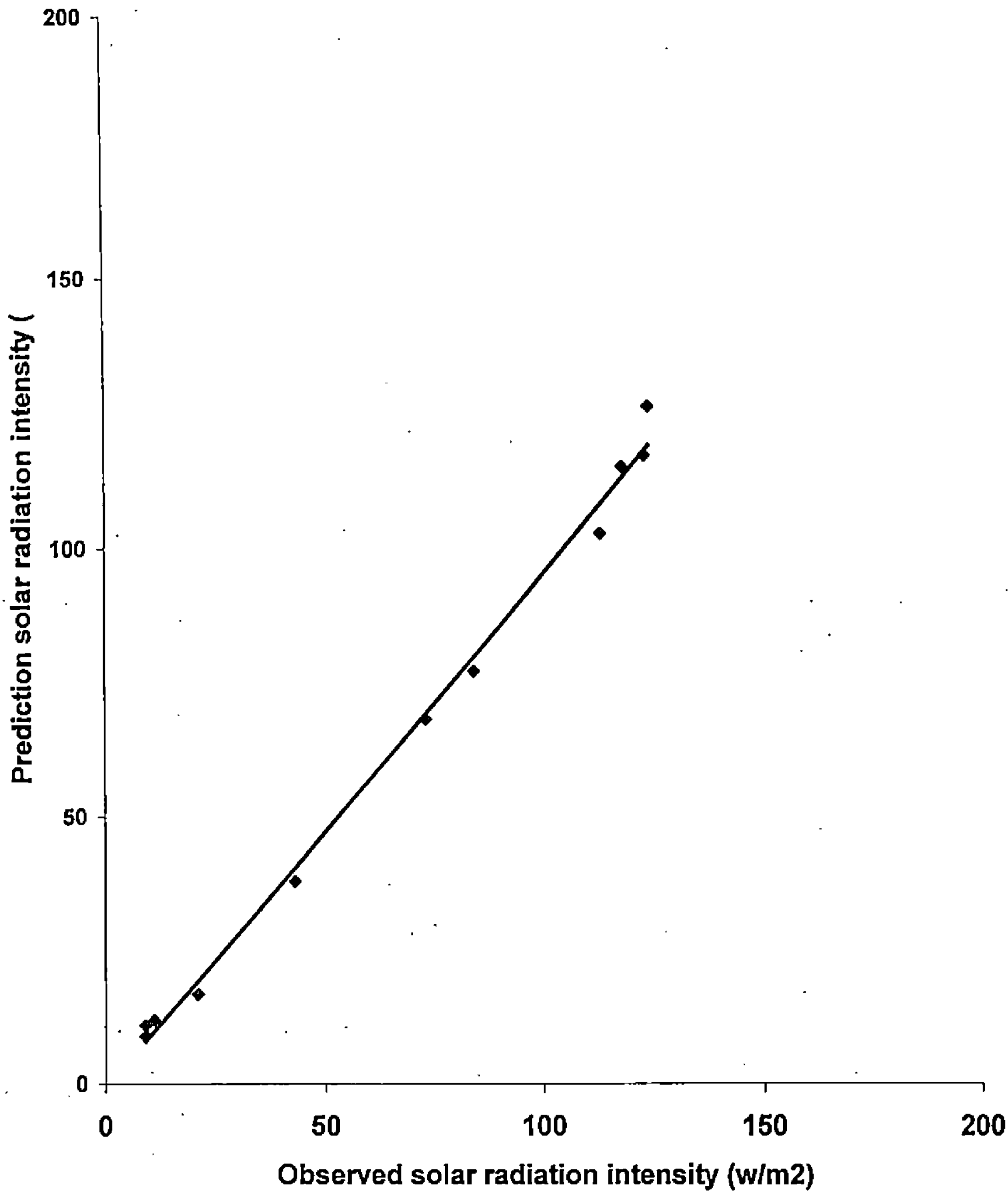

Fig.17 Observed vs predicted solar radiation intensity under the B50 shade net

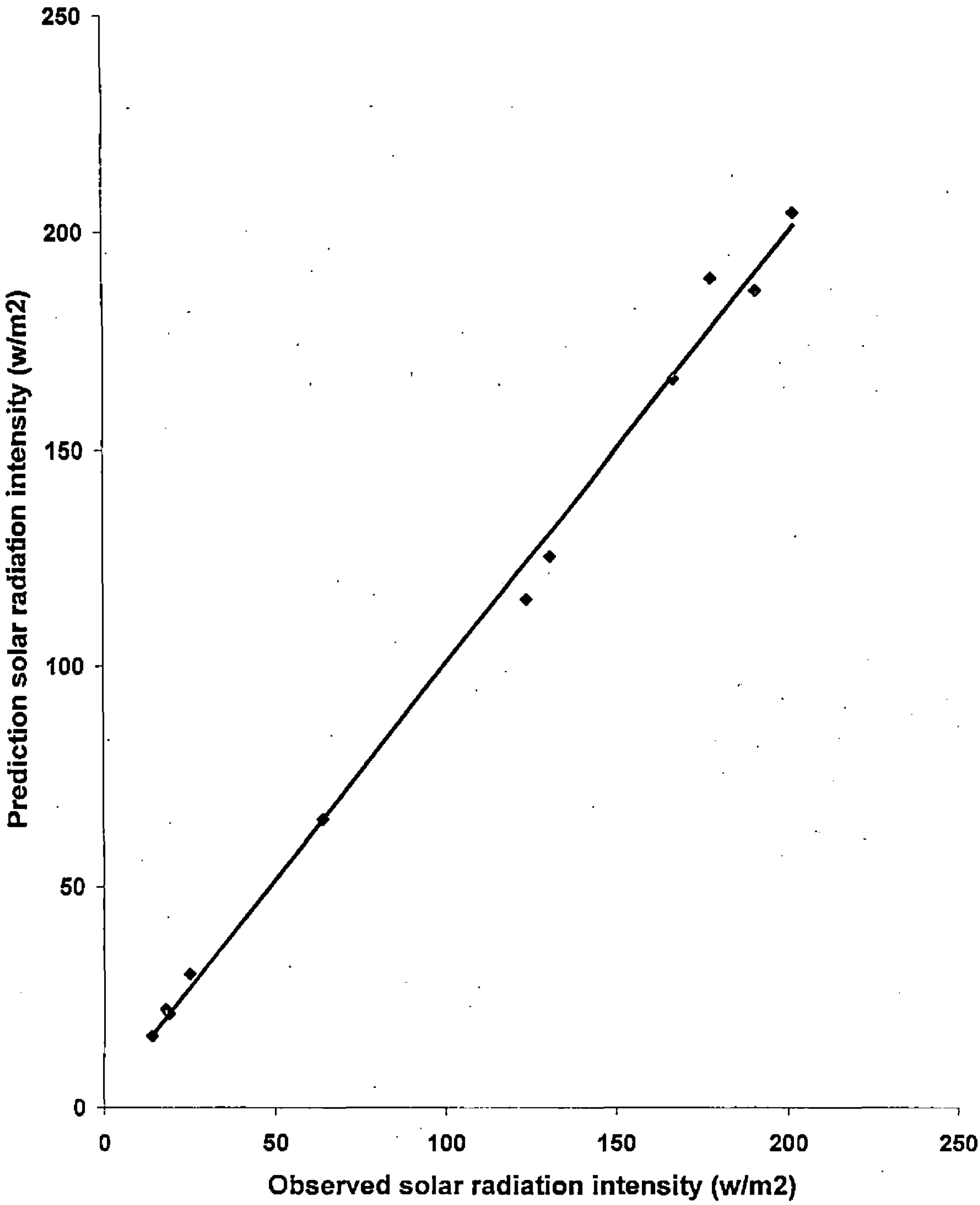

Fig.18 Observed vs predicted solar radiation intensity under the G75 shade net

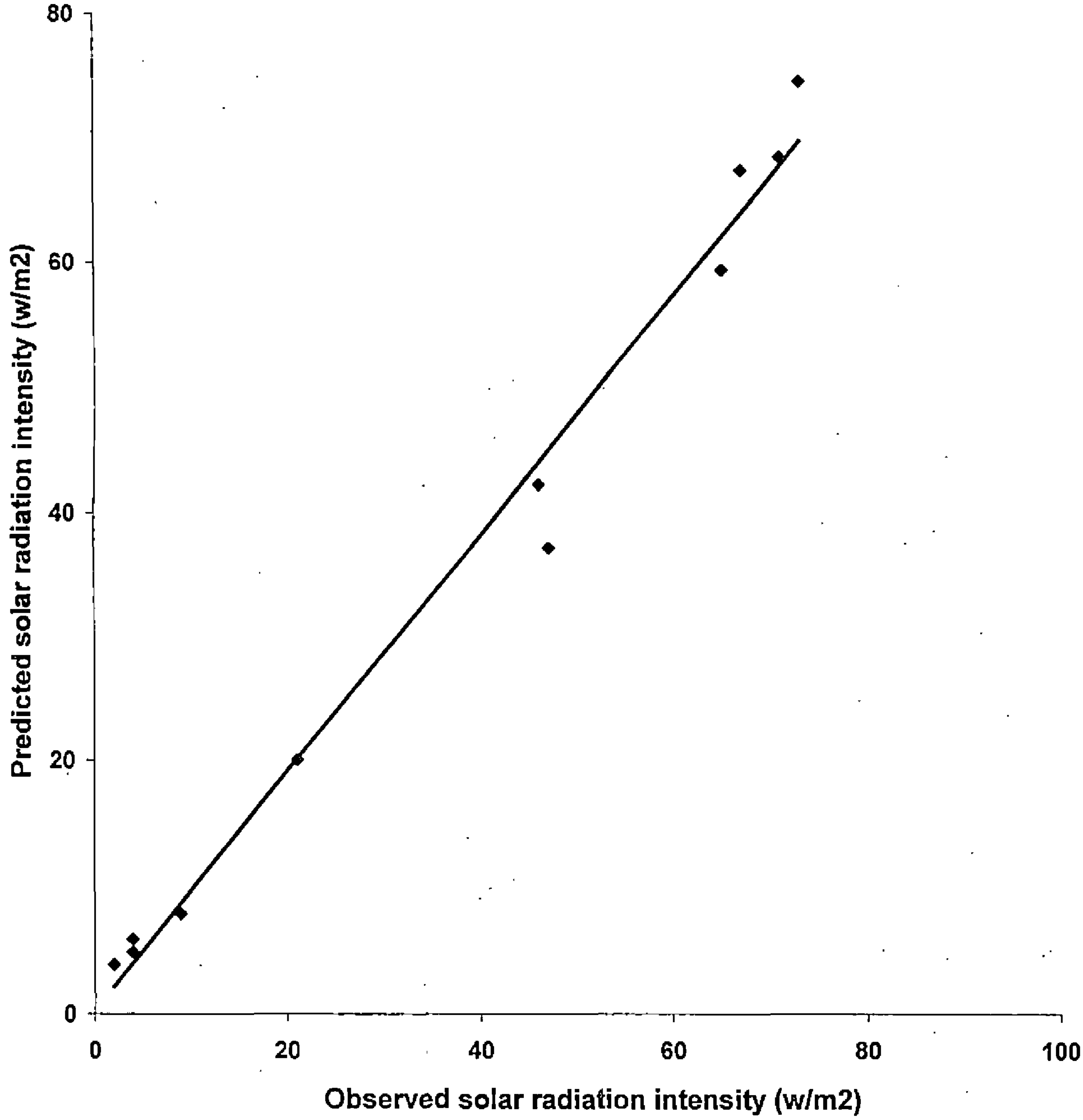

Fig.19 Observed vs predicted solar radiation intensity under the B75 shade net

Table 19. Weekly average daily outside light intensity from 7.30 am to 5.30 pm during the 10 weeks from 01.03.1995 to 09.05.1995.

	Light intensity (x 100 lux)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	65	131	677	981	1119	1135	1108	1007	808	370	57
II	79	98	765	736	1042	995	1122	839	490	285	144
III	108	187	873	1025	1153	1088	1151	1013	682	191	50
IV	107	218	798	813	951	1151	955	955	783	259	100
V	119	361	677	938	1266	920	975	1077	559	310	93
VI	212	441	497	1145	1206	1220	1204	1042	593	289	97
VII	211	526	843	1126	256	1105	1122	754	572	185	4
VIII	166	346	701	887	1281	1086	908	955	546	262	84
IX	121	487	737	796	988	1023	773	875	427	282	97
X	149	403	929	1004	1110	1232	1207	1027	200	147	72

Table 20. **Weekly average daily light intensity from 7.30 am to 5.30 pm under the G50 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.**

	Light intensity (x 100 lux)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	25	51	253	388	449	456	444	399	311	117	22
II	31	38	292	279	415	394	450	325	170	79	56
III	42	68	340	407	464	435	463	402	255	38	19
IV	42	86	306	313	374	463	376	376	300	68	39
V	46	93	214	416	485	380	348	381	180	67	35
VI	57	124	181	450	510	494	456	387	198	76	35
VII	33	151	347	472	100	498	493	391	162	78	1
VIII	43	101	242	320	510	452	365	347	184	64	34
IX	49	138	250	303	428	419	336	312	176	107	39
X	60	126	343	386	462	490	483	412	78	61	27

Table 21. Weekly average daily light intensity from 7.30 am to 5.30 pm under the B50 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.

	Light intensity (x 100 lux)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	11	22	109	173	202	205	200	179	137	45	9
II	13	16	128	122	186	176	203	143	70	28	23
III	18	26	151	182	209	195	209	180	111	10	8
IV	18	38	135	138	167	209	168	168	132	22	17
V	17	39	105	186	235	174	153	135	78	32	16
VI	57	124	181	450	510	494	456	387	198	76	35
VII	14	45	132	142	47	274	282	124	51	30	0
VIII	21	39	114	170	234	217	128	132	48	31	14
IX	24	43	132	144	191	210	133	141	64	48	17
X	24	55	171	183	197	218	216	192	42	25	12

Table 22. **Weekly average daily light intensity from 7.30 am to 5.30 pm under the G75 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.**

	Light intensity (x 100 lux)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	17	37	178	274	317	322	314	282	219	82	15
II	21	27	206	197	293	278	318	229	119	55	41
III	30	47	240	288	328	307	327	284	180	26	13
IV	30	63	216	221	264	327	265	266	211	47	28
V	34	80	159	291	390	261	226	218	112	54	22
VI	53	106	135	368	386	341	238	189	118	63	23
VII	25	143	196	335	69	367	371	236	106	40	1
VIII	38	92	194	283	420	361	247	152	97	54	22
IX	39	115	208	239	334	323	255	172	68	63	27
X	42	94	255	278	318	362	345	279	62	44	20

Table 23. Weekly average daily light intensity from 7.30 am to 5.30 pm under the B75 shade net during the 10 weeks from 01.03.1995 to 09.05.1995.

	Light intensity (x 100 lux)										
	7.30	8.30	9.30	10.30	11.30	12.30	1.30	2.30	3.30	4.30	5.30
I	7	15	64	106	124	126	123	109	82	23	6
II	9	11	76	72	114	108	125	86	39	18	17
III	12	17	91	112	129	120	129	110	65	9	5
IV	12	11	81	83	101	129	102	102	79	18	11
V	14	18	51	94	146	107	106	76	36	25	9
VI	11	15	51	124	211	142	126	110	43	21	9
VII	7	21	61	119	32	146	153	105	32	19	0
VIII	11	19	41	94	152	129	47	74	26	16	9
IX	16	26	54	86	126	131	81	82	28	26	13
X	16	27	101	110	129	135	133	110	27	19	9

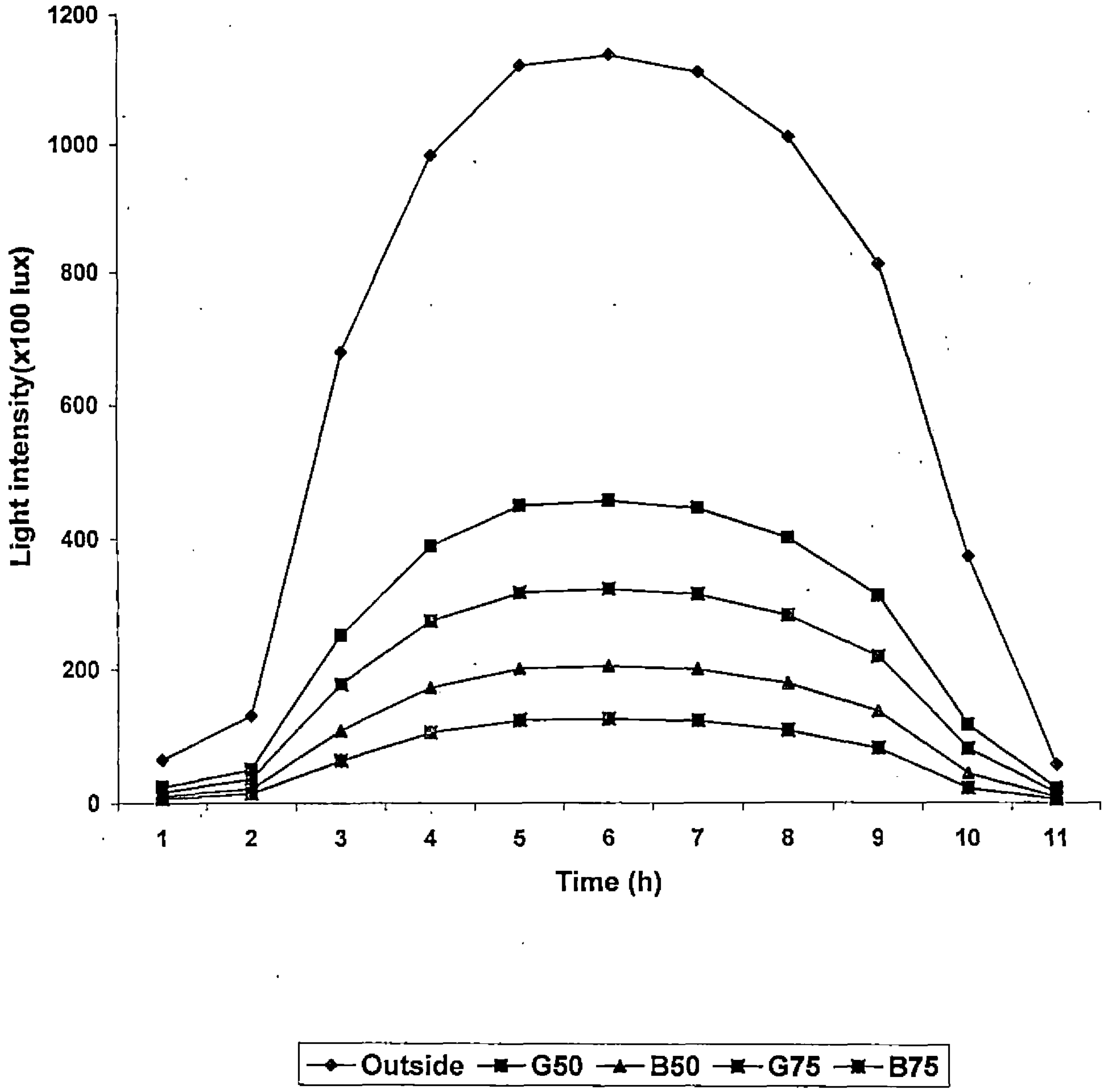

Fig.20 Weekly average daily variation of inside and outside light intensities during the I week (1.3.95 to 7.3.95)

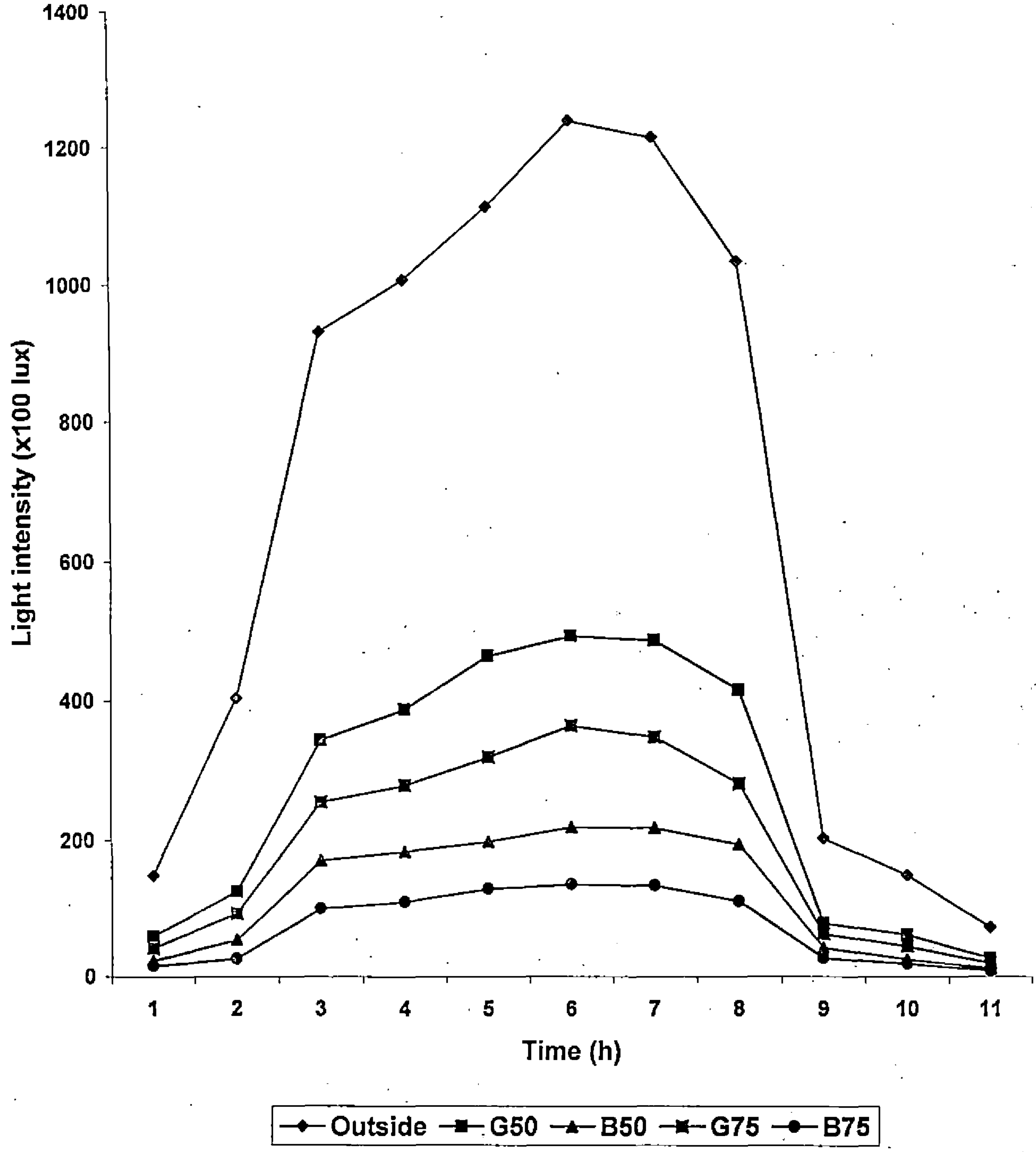

Fig.21 Weekly average daily variation of the inside and outside light intensities during the X week (3.5.95 to 9.5.95)

range of variation under the G50 net was 300 x 10^2 – 500 x 10^2 lux. The corresponding ranges under the B50, G75 nets were 120 x 10^2 – 270 x 10^2, 200 x 10^3 – 400 x 10^3 lux and 50 x 10^2 – 200 x 10^3 lux respectively.

In the open space, the observed maximum light intensity was 1266 x 10^2 lux and that under the G50 net was 510 x 10^2 lux. The maximum observed intensities under the B50, G75 and B75 nets were 274 x 10^2, 420 x 10^2 and 142 x 10^2 lux respectively. The maximum light intensities under G50, B50, G75 and B75 nets were 40.3 per cent, 21.6 per cent, 33.2 per cent and 11.2 per cent respectively of the light intensity in the open space. At noon the average light intensity in the open space was 1095 x 10^2 lux. The corresponding light intensities under the G50, B50, G75 and B75 nets were 448 x 10^2, 214 x 10^2, 325 x 10^2 and 127 x 10^2 lux respectively.

As the intensity of shading increases the light intensity always decreases. Also under the black net, the light was much less than that under the green net.

4.4.1 Relationships between the Inside and Outside Light Intensities

A linear relationship was observed between the outside and inside light intensities. The slope of the line varied at outside light intensity equal to 150x10^2. Considering the outside light intensity as the dependent variable and inside light intensity as the independent variable, regression analysis was done and the relationships between the inside lead outside light intensities were obtained. The equations are,

For G50 shade net, when the outside light intensity is less than or equal to 150 x 10^2 lux, the equation was

$y = 0.398\ x - 84.6$ (correlation coefficient, $r = 0.99$)

For G50 net, when the outside light intensity is more than 150 x 10^2 lux, the equation was

$y = 0.439\ x - 4298$ (correlation coefficient, $r = 0.99$)

For B50 shade net, when the outside light intensity is less than or equal to 150×10^2 lux, the equation was

$y = 0.173\ x - 61.6$ (correlation coefficient, $r = 0.98$)

For B50 shade net, when the outside light intensity is more than 150×10^2 lux, the equation was

$y = 0.206\ x - 2928$ (correlation coefficient, $r = 0.95$)

For G75 shade net, when the outside light intensity is less than or equal to 150×10^2 lux, the equation was

$y = 0.297\ x - 206.7$ (correlation coefficient, $r = 0.98$)

For G75 shade net, when the outside light intensity is more than 150×10^2 lux, the equation was

$y = 0.311\ x - 3137$ (correlation coefficient, $r = 0.95$)

For B75 shade net, when the outside light intensity is less than or equal to 150×10^2 lux, the equation was

$y = 0.125\ x - 111.4$ (correlation coefficient, $r = 0.97$)

For B75 shade net, when the outside light intensity is more than 150×10^2 lux, the equation was

$y = 0.132\ x - 2399$ (correlation coefficient, $r = 0.94$)

Using these equations the tenth week's light intensities under the four shading conditions were predicted and were plotted against the observed values (Figs 22 to 25). The observed and predicted values are given in Table 24. The

Table 24. **Observed and predicted weekly average daily light intensities for the X week under the four shade nets.**

Light intensity (x 100 lux)								
	G50		B50		G75		B75	
Time (h)	Obs. Values	Pred. Values	Obs. Values	Pred. Values	Obs. Values	Pred. Values	Obs. Values	Pred. Values
7.30	60	58	24	25	42	42	16	18
8.30	126	134	55	54	94	94	27	29
9.30	343	365	171	162	255	257	101	99
10.30	386	397	183	177	278	281	110	108
11.30	462	444	197	199	318	313	129	122
12.30	490	497	218	224	362	351	135	139
1.30	483	486	216	219	345	344	133	135
2.30	412	407	192	182	279	288	110	112
3.30	78	79	42	34	62	57	27	24
4.30	61	57	25	25	44	41	19	17
5.30	27	28	12	12	20	19	9	8

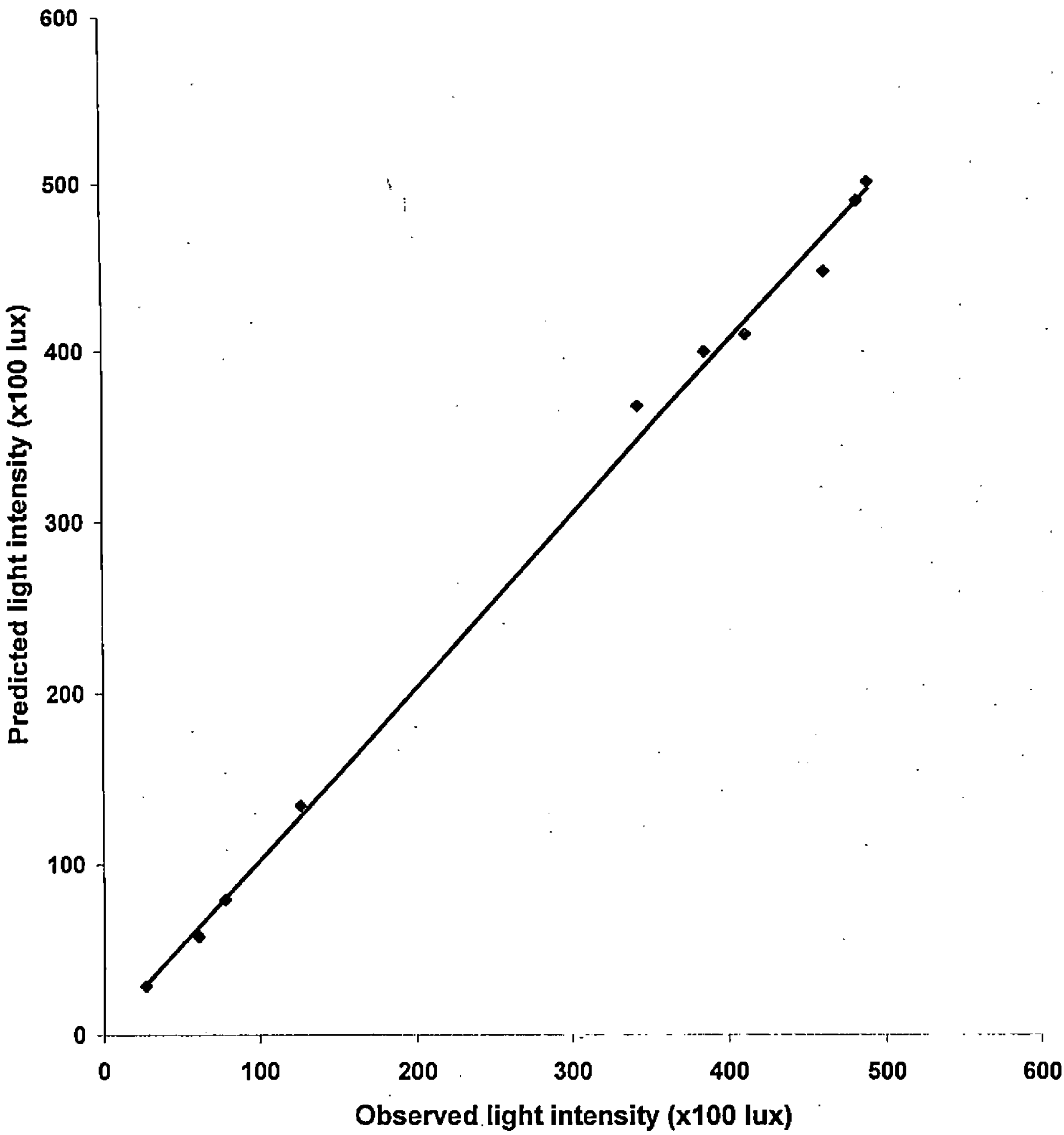

Fig.22 Observed vs predicted light intensity under the G50 shade net

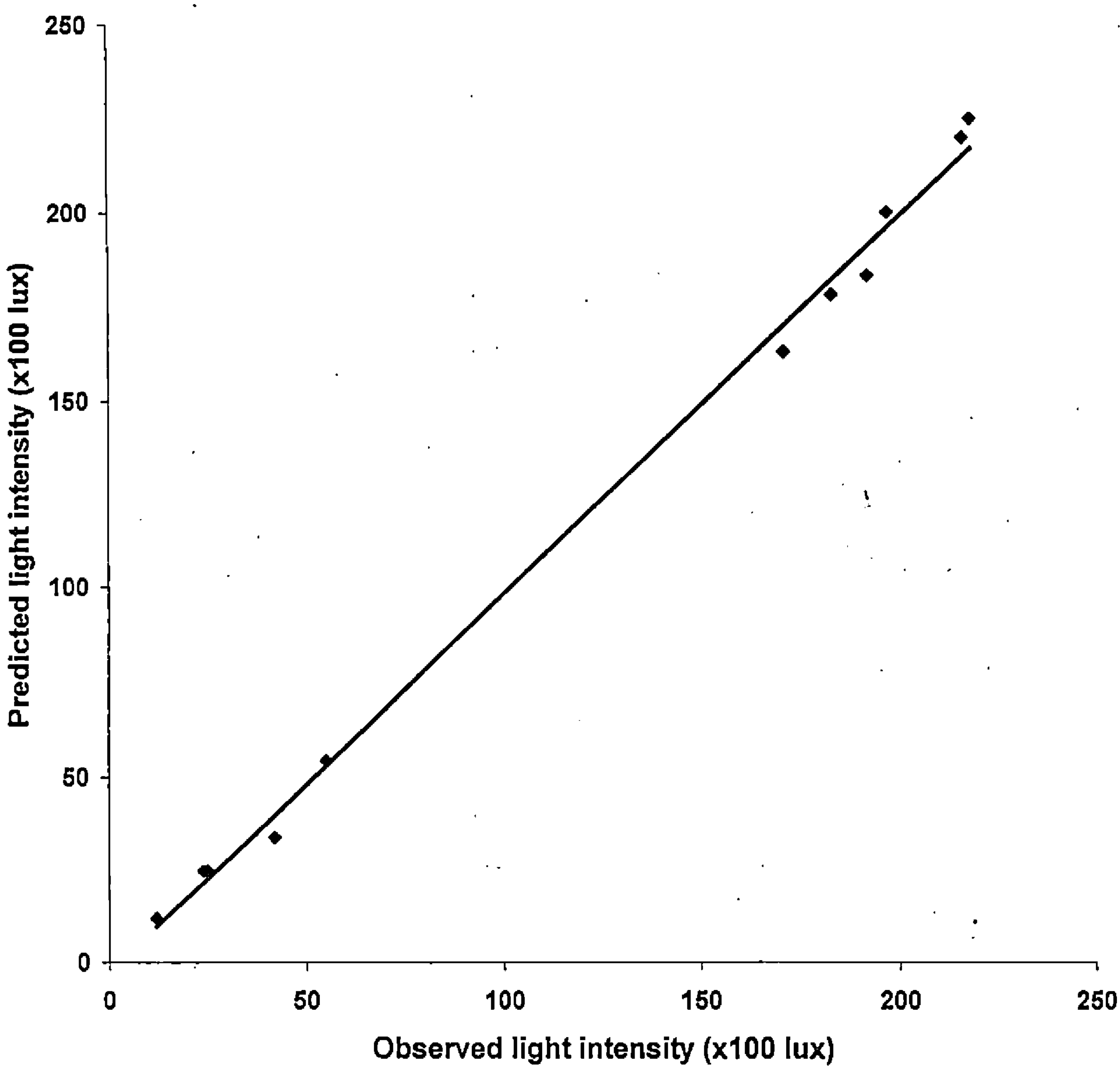

Fig.23 Observed vs predicted light intensity under the B50 shade net

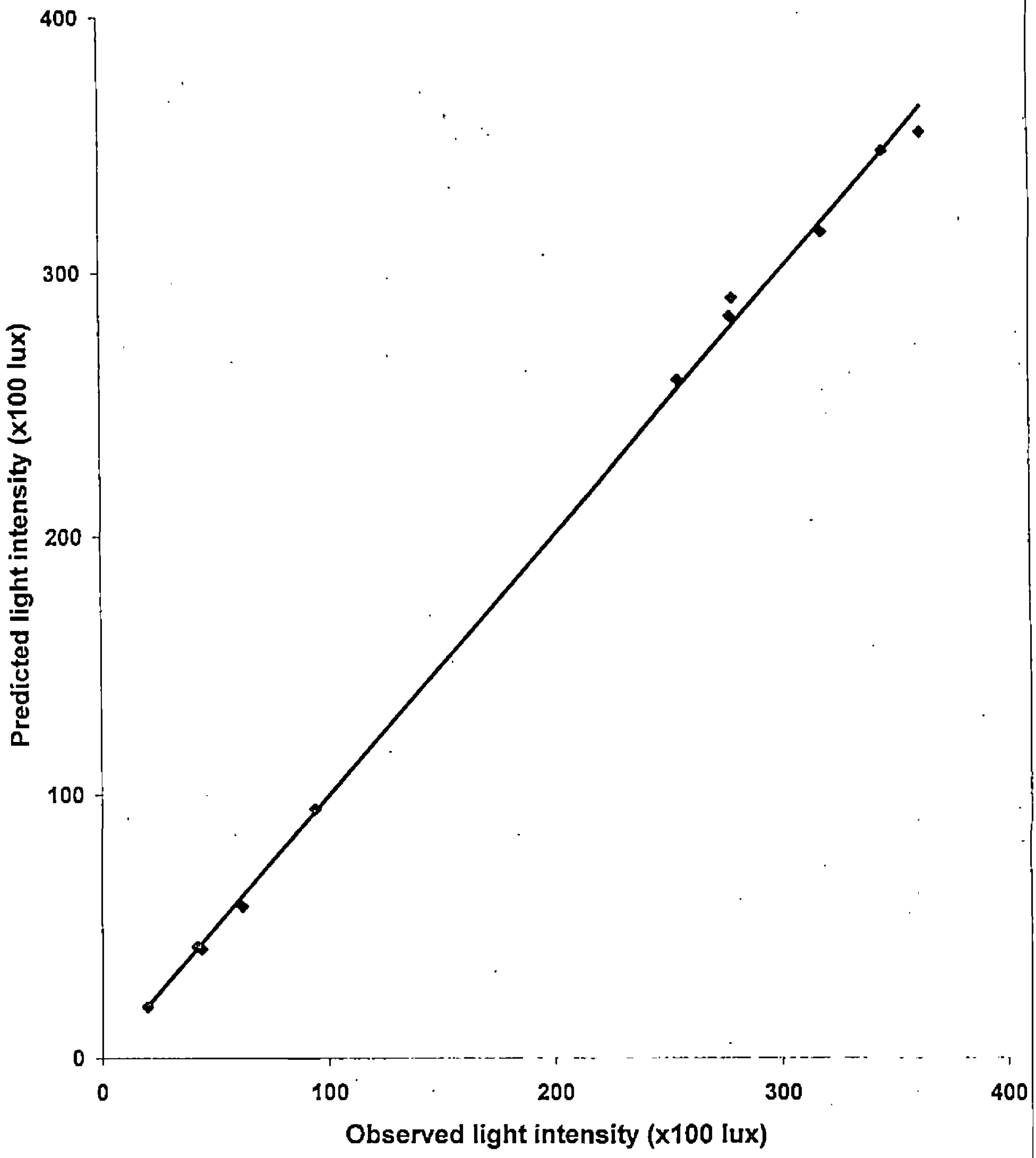

Fig.24 Observed vs predicted light intensity under the G75 shade net

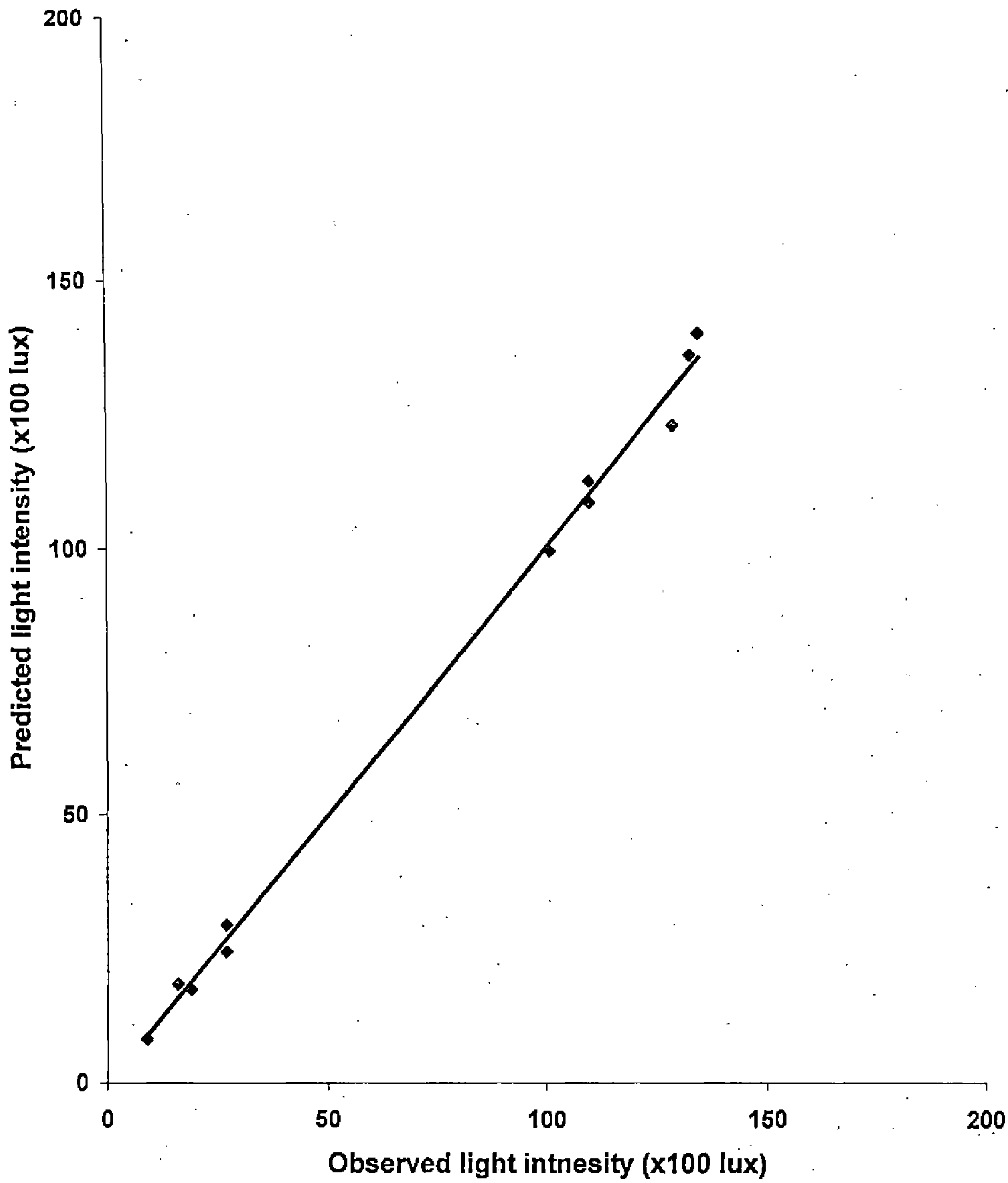

Fig.25 Observed vs predicted light intensity under the B75 shade net

straight lines with 1:1 slopes indicate good correlation between observed and predicted values.

A computer program in 'BASIC' was developed to predict the environmental parameters under the four shade nets based on the outside conditions and is given in Appendix IV.

4.5 EFFECT OF SHADING ON THE GROWTH OF TOMATO

The height of the plants, number of leaves and stem diameter were the observed growth parameters of tomato.

Fig.26 shows the variation of height of plants under different shading conditions. The heights of the plants under the shades were always greater than that in the open space. Initially the heights of the plants under the green nets were more than that under the black. There was no much difference between the plant heights under G50 and G75 on 05.03.1995 and 17.03.1995. Thereafter the height increased, as the intensity of shading increased. On 26.03.1995 and 10.04.1995 the maximum height was observed under the B50 net. From the graph it is clear that the height of tomato plants under shades will be more than that in the open space and the height increases in proportional to the intensity of shading. Under B75 net the plant height was 64 per cent of that in the open space.

Fig.27 shows the variation in stem diameter under different shading conditions. The stem diameter was always greater in the open space compared to those under shades. Of the four shade conditions tested, the stem diameter was more under the G50 shade net. There was not much difference between the stem diameter of plants under the B50 and G75 nets. The G50 net reduced the stem diameter to 82.8 per cent of that in the open space. The corresponding reduction in stem diameter under B50, G75 and B75 nets were 71.8 per cent, 75 per cent and 64 per cent respectively.

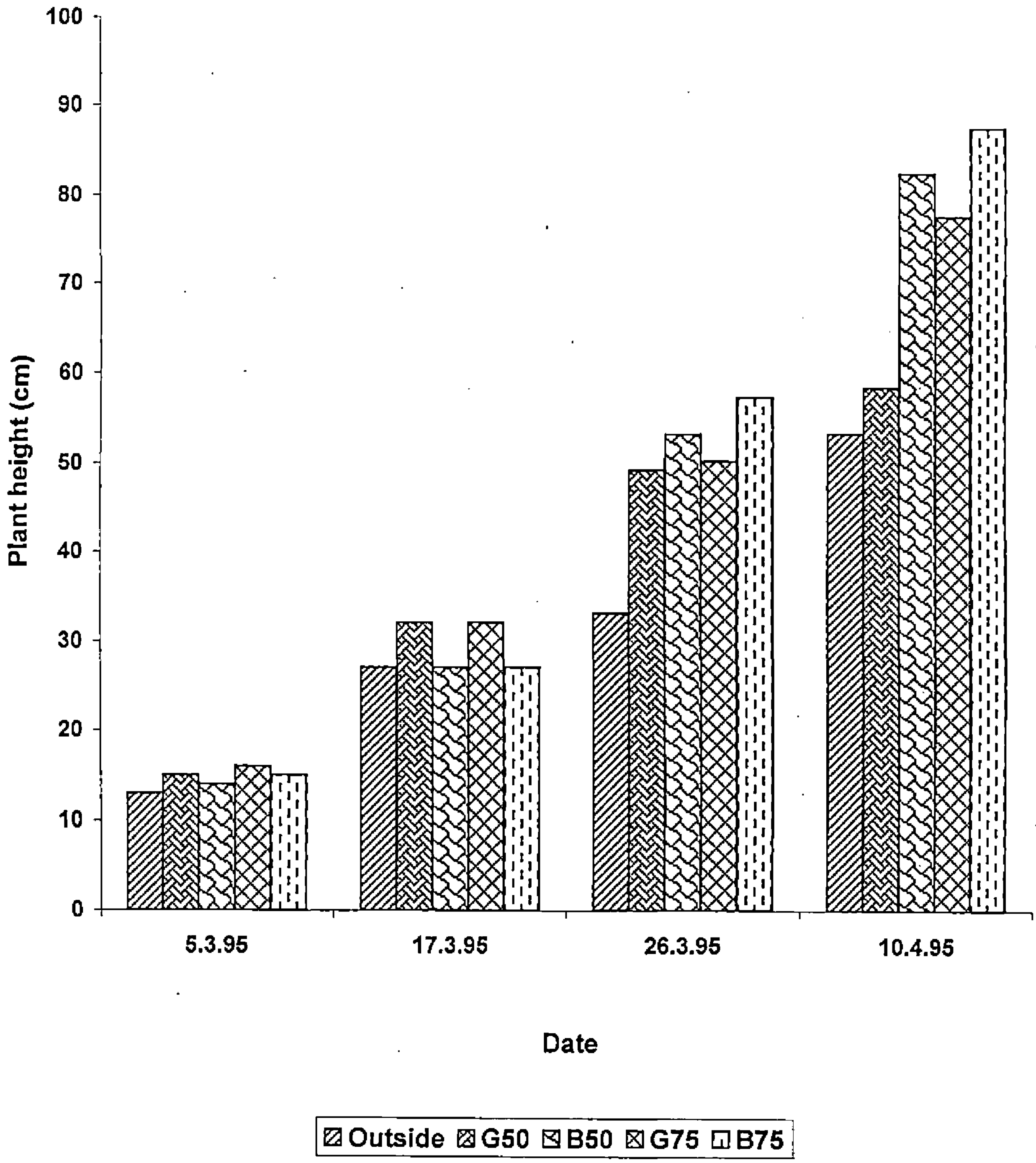

Fig.26 Variation in plant height of tomato under shades

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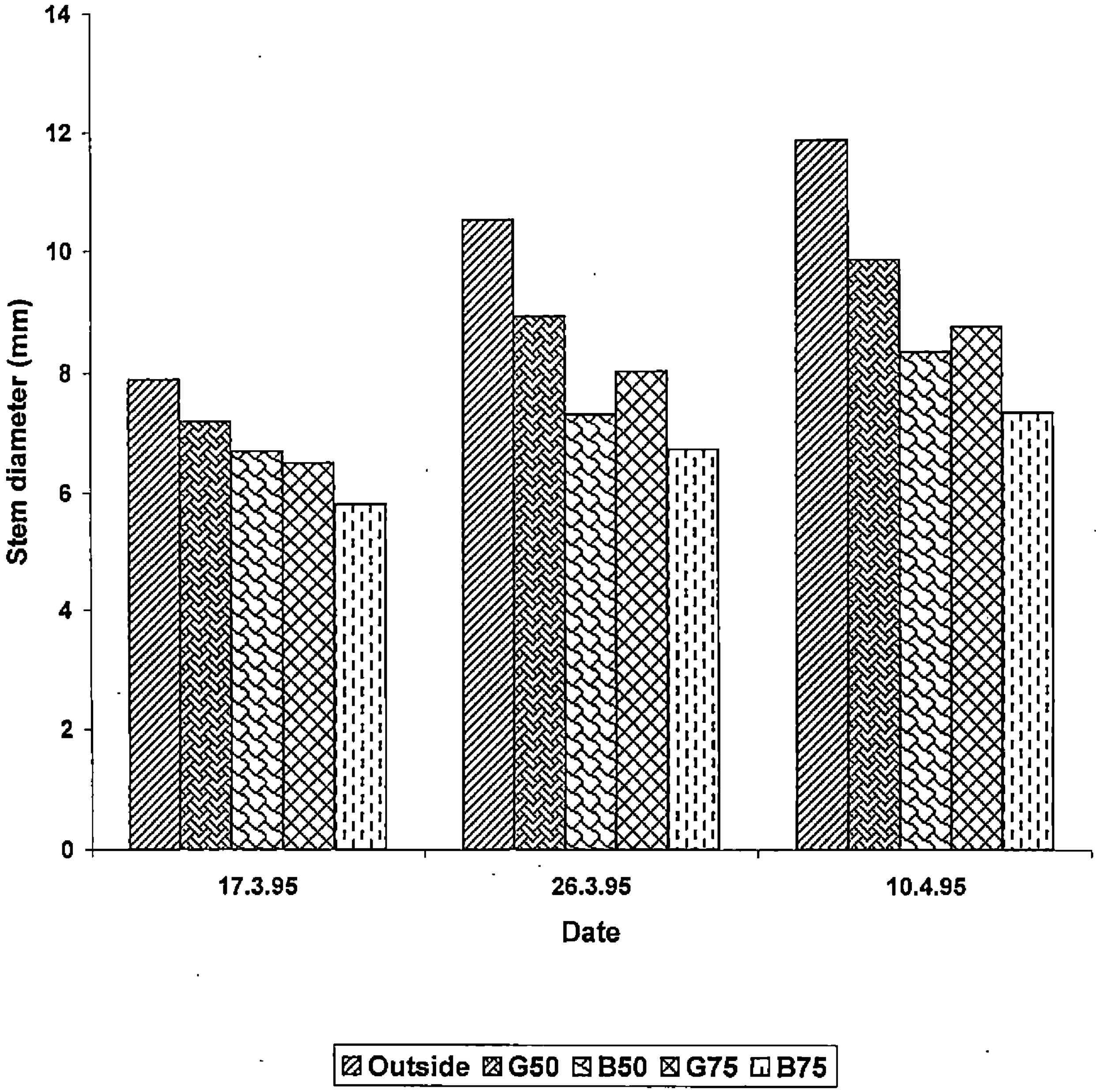

Fig.27 Variation in stem diameter of tomato under shades

Fig.28 shows the number of leaves of plants grown with and without shading. The numbers of leaves were more in the plants grown without shading. Comparing the shading effects of the nets, there was not much difference in the number of leaves between the plants grown under the three shade nets. The numbers of leaves were comparatively more in the plants grown under G75 net.

4.6 EFFECT OF SHADING ON THE GROWTH AND YIELD OF AMARANTHUS

The observed growth parameters were the plant height, stem diameter and the number of leaves. The yield was also tested.

Fig.29 shows the variation of plant height under different shades. The heights of the plants grown under shades were always more than those in the open space. Of the four shading conditions tested, plants under G50 net were taller than others.

The variation of stem diameter under shades is shown in Fig.30. The stem diameter was always greater under G50 shade net. Compared to B50 and G75 nets, plants grown outside were having ore than stem diameter. The stem diameter was always least under B75 net.

Fig.31 shows the variation in number of leaves on plants grown under shades. The numbers of leaves were highest under G50 net. The numbers of leaves were very less in plants grown under G75, B50 and B75 nets. There was not much difference in number of leaves between the plants grown outside and under G50 net.

Considering the above three growth parameters, the growth of amaranthus was best under G50 net. The plants grown outside grew much better than those under G75, B75 and B50 nets.

The variation in yield of amaranthus is shown in Fig.32. The yield was highest under G50 net. The yield was much lower under G75, B75 and B50 nets compared to G50 and plants grown without shade.

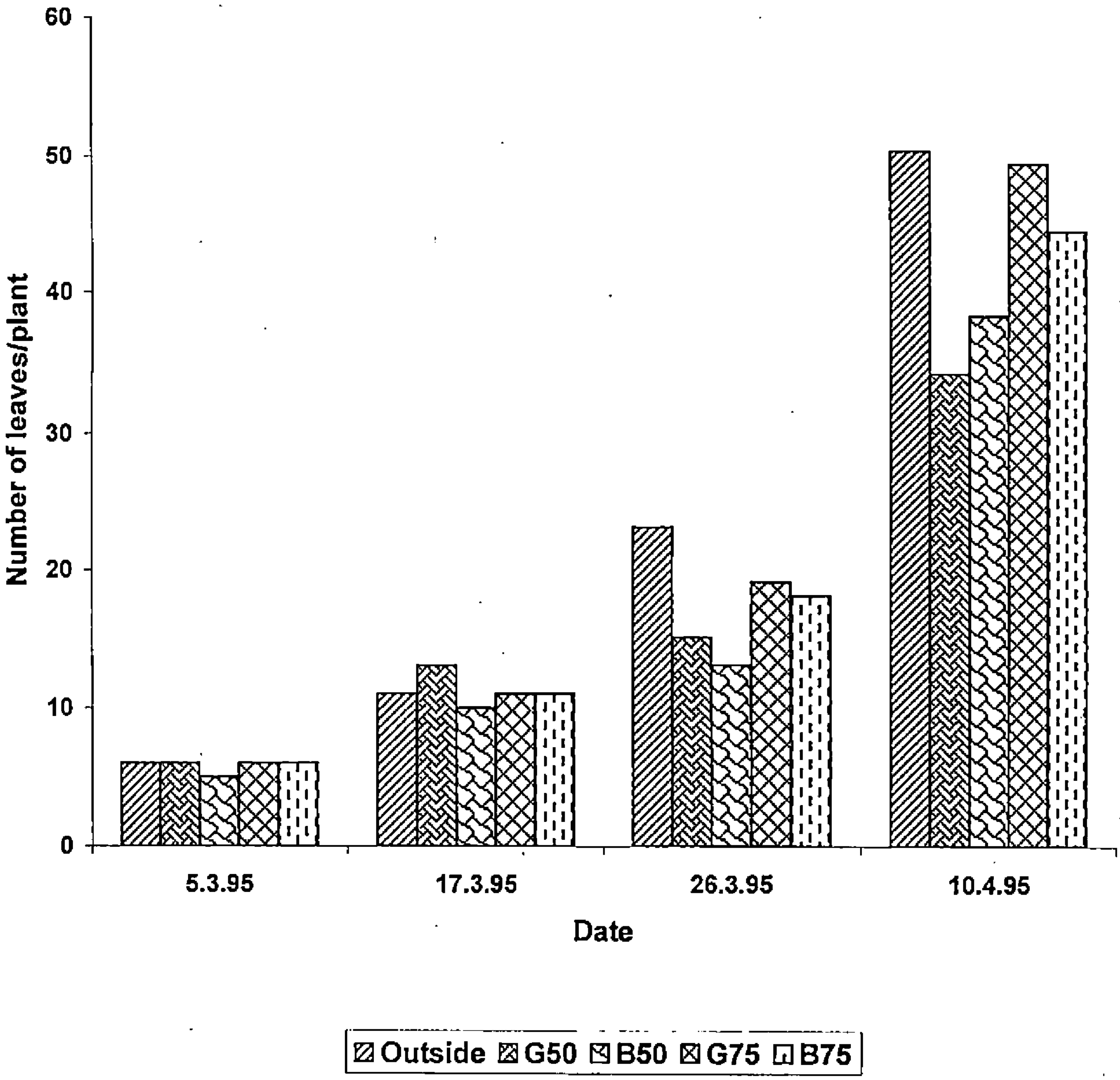

Fig.28 Variation in number of leaves of tomato under shades

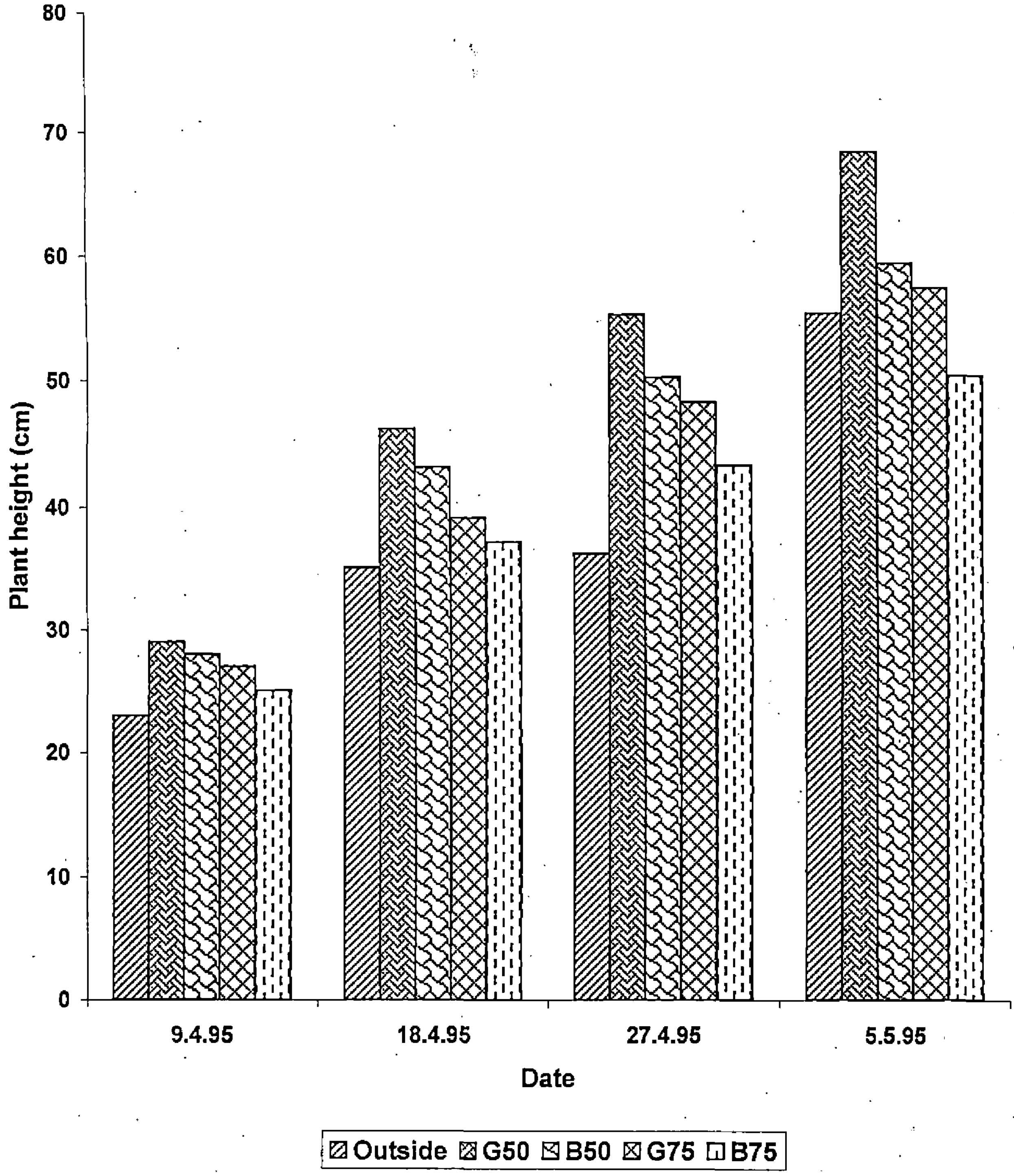

Fig.29 Variation in plant height of Amaranthus under shades

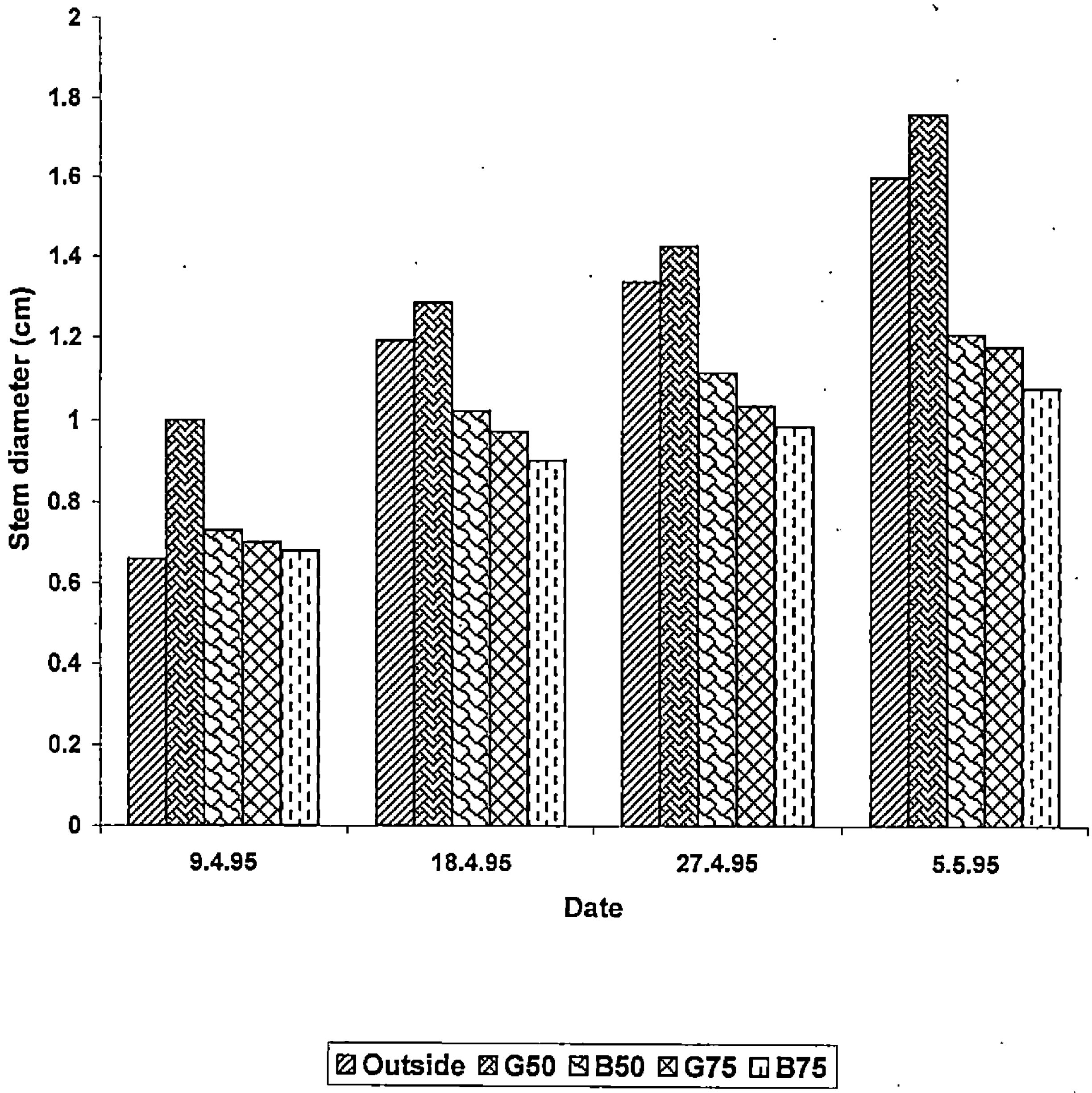

Fig.30 Variation in stem diameter of Amaranthus under shades

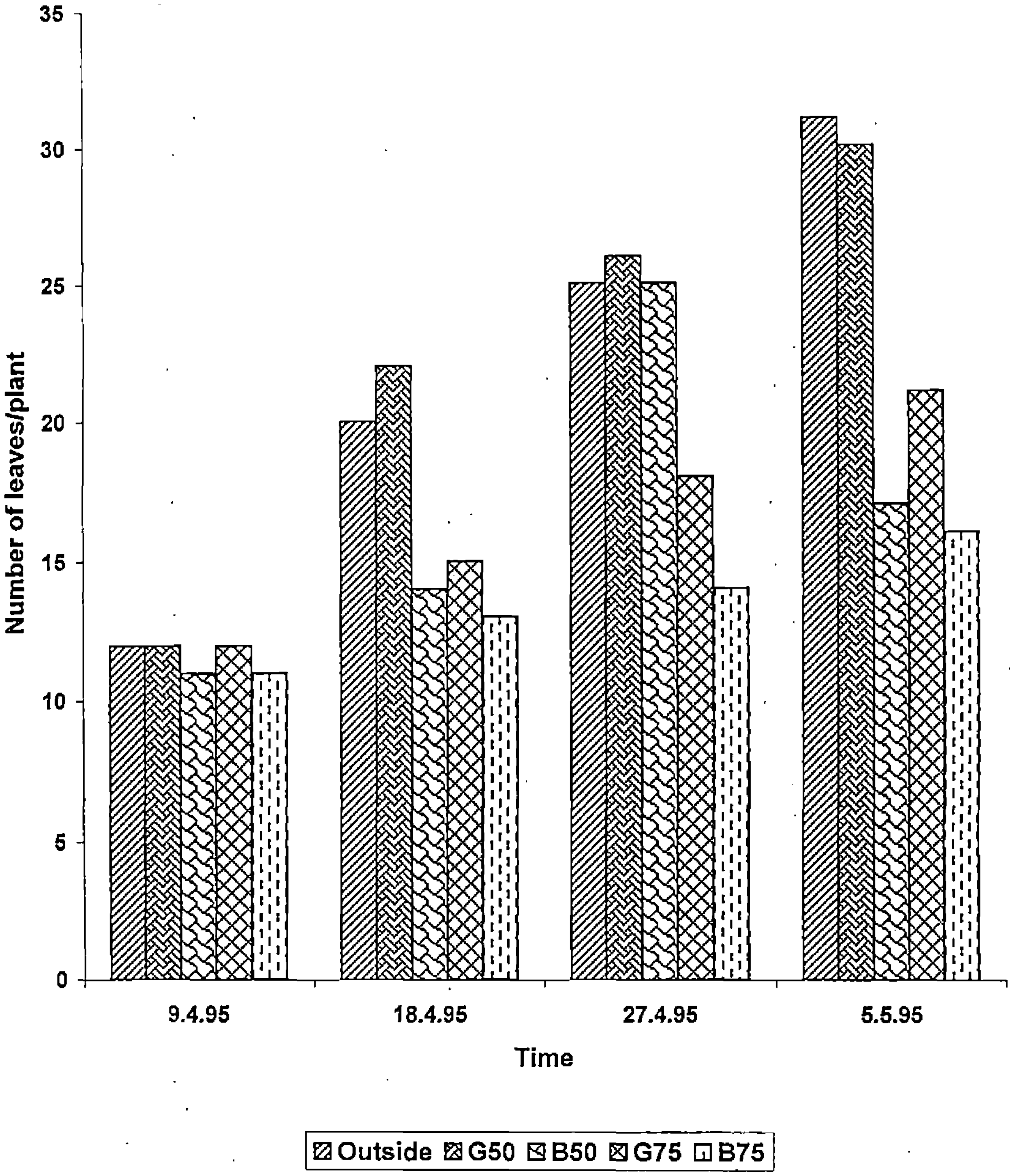

Fig.31 Variation in number of leaves of Amaranthus under shades

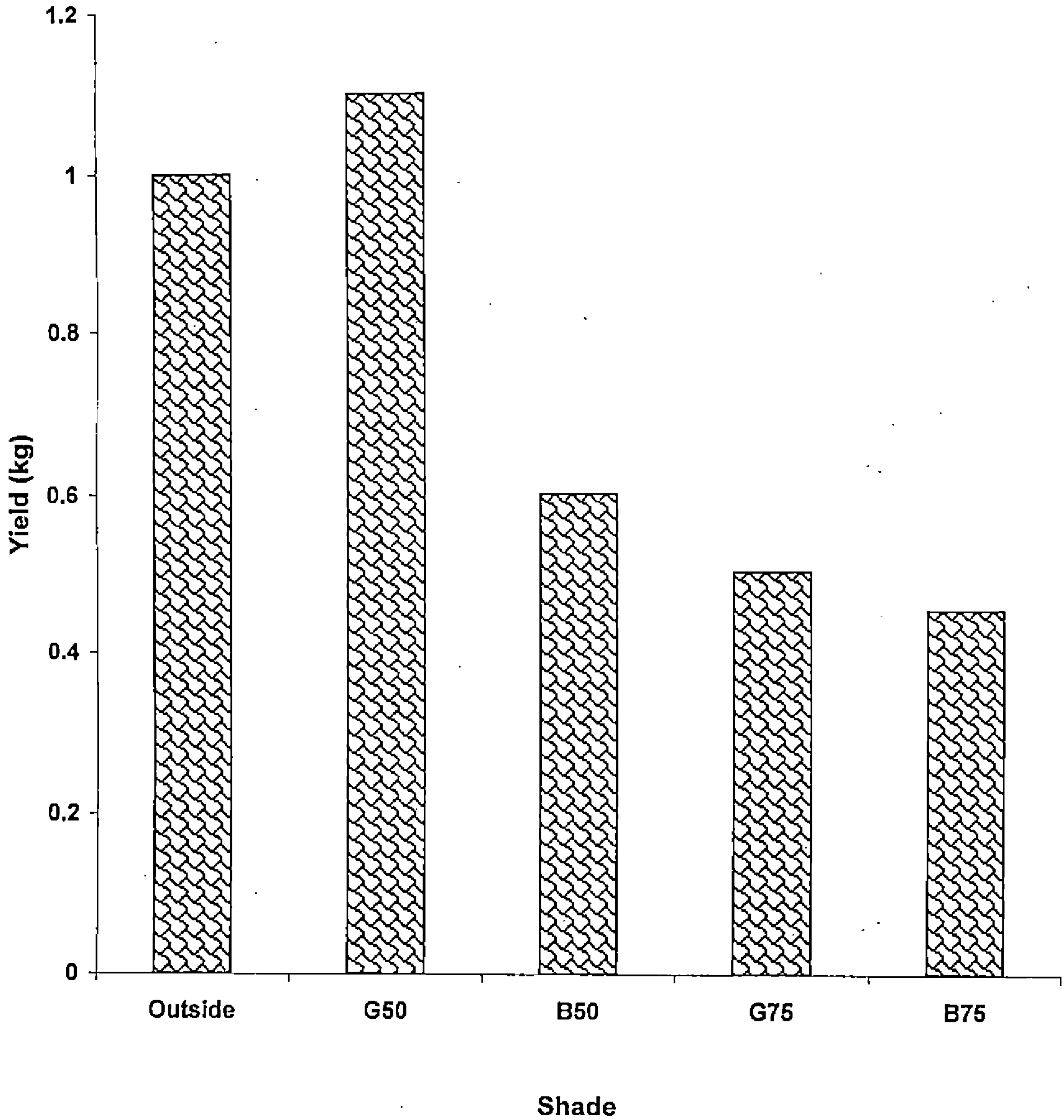

Fig.32 Variation in yield of Amaranthus under shades

Summary

SUMMARY

Controlled environment agriculture is one of the promising measures for supplying food under unfavourable conditions. Shade houses, greenhouses, low tunnels and cloches are different forms of controlled environment agriculture practised at commercial levels in many countries among which shade house is a cheaper method of environmental control though the degree of control is less.

Shades of different intensities can be provided by using agro shade nets, which is made of high density polyethylene plastic treated with best known UV stabilizers. Analysing the shading effects of these nets, crops can be grown under optimum light intensity, temperature and humidity which vary from crop to crop.

The agro shade nets are now used in large scale for the vegetative propagation of seeds and plants and for growing ornamental plants. Considering the prospects of growing crops under shades, the thesis entitled, 'Effect of different shadings on the environmental parameters' was undertaken. The main objectives were (1) to study the variation in light intensity under different shading conditions, (2) to study the variation in the intensity of solar radiation under different shading conditions, (3) to study the variation in temperature and relative humidity under different shading conditions, (4) to study the crop response to the different intensities of light, temperature and humidity under different shading conditions.

Four structures of size 6 m x 4 m x 2 m were constructed. They were oriented east-west parallel to each other to maintain better light level. Those structures were rectangular with flat top. The shade nets used for this study were green net of 50 per cent shade, green net of 75% shade, black net of 50% shade and black net of 75% shade. These nets were spread over the structures and were extended to 0.5 m along all the sides.

The environmental conditions created under the shade nets were studied. The parameters monitored included dry bulb temperature, wet bulb temperature, intensity of solar radiation and intensity of light. These were recorded at one hour interval from 7.30 a.m. to 5.30 p.m. for about ten weeks both under the shades and in the open space. Two crops namely tomato and amaranthus were tested under the shades and the growth was compared with those in the open space field. The growth parameters monitored included plant height, stem diameter and number of leaves.

The intensity of solar radiation was measured using a solar radiation monitor, which indicated that the solar radiation in the total range in Watt/m^2/sec. Lux meter was used to measure the solar radiation in the photosynthetically active radiation (0.4 to 0.7 microns) range. The unit of measurement was lux.

Always the temperature under the green shade nets of 50% to 75% shade and black net of 75% shade were lower than the outside temperature. At outside temperatures less than 29°C, the black net with 50% shade raised the temperature to a small extent. At higher temperatures, this shade net also lowered the temperature. Comparing the shading effects of the four shade nets on temperature, the highest temperature was always under the B50 shade net and the lowest was under the G75 shade net. There was no much difference in temperature under B75 and G50 shade nets. The temperature increased with increased intensity of shading and the temperatures under the black nets were always higher than that under the green nets.

From the dry bulb and wet bulb thermometer readings, the relative humidity was calculated both under shades and in the open space. The relative humidity under the nets was always higher than that in the open space. Of the four shading conditions studied the highest RH was under G75 shade net and lowest was under the B50 shade net. The RH under B75 and G50 shade nets were always in between of which higher RH was under B75 shade net. The relative humidity increased with increased shade intensities. The RH values under the green nets were higher than under the black nets.

All these nets lowered the temperature and raised the RH, and therefore evapotranspiration from crops grown under shades will be less.

The patterns of variation of solar radiation intensity under all the shade nets were similar to that in the open space. All the shade nets lowered the solar radiation intensity. Comparing the shading effects of the four shade nets studied, the highest solar radiation intensity was observed under G50 shade net and a lowest was under B75 shade net. Always the intensities under the green nets were higher than that under the black nets. The solar radiation intensity was reduced with increased intensity of shades.

The variations of light intensity under the shade nets were similar to the variation of solar radiation intensity. The highest light intensity was under G50 net and the lowest under B75 net. The maximum light intensity observed in the open space was 1266×10^2 lux whereas the maximum intensity under the G50, B50, G75 and B75 nets were 510×10^2, 420×10^2 and 142×10^2 respectively.

Regression analysis was done to develop relationships between the environmental parameters under the shades and in the open space. The equations were developed with higher correlation coefficients. A computer program was developed to predict the environmental parameters under the shades based on the parameters in the open space.

These equations give a clear idea about the variation in environmental parameters under these four shade nets. As the temperature and light requirements of various plants for the maximum vegetative growth and yield varies, we can select suitable nets for each crop or ornamental plants.

The physiological parameters studied were the variation in height of plants, stem diameter and number of leaves under different shades. The height of tomato and amaranthus were higher under shades compared to those in the open space and the height increased in proportional to the intensity of shading.

The stem diameter of tomato plants grown under shades were less than that in the open space. But for amaranthus, the stem diameter was higher under G50 shade net. Also the numbers of leaves of tomato under shades were less compared to those in the open space. For amaranthus, number of leaves and yield were highest under G50 net. The yield in the open space was higher compared to the yield under the other three nets.

From these observations it is clear that the vegetative growth of tomato is better in the open space compared to those under these shade nets in our local climatic condition. Amaranthus grows better under G50 net and yield will be also higher under this net. Cultivation in the open space is better compared to other three shade nets studied.

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Appendices

APPENDIX – 1

Materials used and their cost

Item	Rate	Quantity required/structure	Cost
1. GI pipe (1 ¼" diameter)	Rs.70/m	15 m	Rs.1050/-
2. GI stay wire (14 gauge)	Rs.24/kg	1½ kg	Rs.36/-
3. G50 shade net	Rs.24/m^2	45 m^2	Rs.1080/-
4. B50 shade net	Rs.22/m^2	45 m^2	Rs.990/-
5. G75 shade net	Rs.26/m^2	45 m^2	Rs.1170/-
6. B75 shade net	Rs.25/m^2	45 m^2	Rs.1125/-
7. Concrete	Rs.620/m^3	0.589 m^3	Rs.365/-

APPENDIX – II

Specification of the solar radiation monitor

Range : 0 to 1200 W/m^2, + 1%

Display : Digital with recorder output in the range 0 to 100 mv.

Power : 1. internal : 9V battery

2. external : 9 to 12V battery eliminator

Sensor : Remote operated type – photo diode.

APPENDIX – III

Specification of the lux meter

Measurement	:	Lux, Ft-candle.
Ranges	:	Lux – 0 to 5,00,000 lux, 3 ranges, Ft-candle – 0 to 50,000 Ft-candle, 3 ranges
Zero adjustment	:	Automatic adjustment.
Sampling time	:	Approximately 0.4 second
Sensor material	:	Selenium Photovoltaic cells
Power supply	:	9V battery
Dimension	:	163 70 30 mm (6.4 2.8 1.2 inch)
Weight	:	220 g (0.52 lb).

APPENDIX - IV

```
10   REM   PROGRAM TO PREDICT THE TEMPERATURE, RH
20   REM   SOLAR RADIATION INTENSITY AND LIGHT
30   REM   INTENSITY UNDER THE SHADE NETS
40   REM   T0-OUTSIDE TEMP. RH0-OUTSIDE RH
50   REM   SRI0-OUTSIDE SOLAR RADIATION INTENSITY
60   REM   LI0-OUTSIDE LIGHT INTENSITY
70         INPUT T0, RH0, SRI0, LI0
80         IF T0> 34 THEN 170
90         TG50=T0*.812+4.61
100        TB50=T0*.786+6.09
110        TG75=T0*.805+4.25
115        TB75=T0*.818+4.28
120        PRINT  "TEMPERATURE UNDER THE B50 SHADE NET = " TB50 "xC"
130        PRINT  "TEMPERATURE UNDER THE G50 SHADE NET = " TG50 "xC"
140        PRINT  "TEMPERATURE UNDER THE G75 SHADE NET = " TG75 "xC"
150        PRINT  "TEMPERATURE UNDER THE B75 SHADE NET = " TB75 "xC"
160        GOTO 220
170        TG50=T0*.956-.36
180        TB50=T0*.92+1.67
190        TG75=T0*.981-2.01
200        TB75=T0*.955-.45
210        GOTO 120
220        RHG50=RH0*.968+7.69
230        RHB50=RH0*.947+6.26
240        RHG75=RH0*.961+16.32
250        RHB75=RH0*.981+13.79
260        IF RHG50 > 100  THEN RHG50 = 100
270        IF RHB50 > 100  THEN RHB50 = 100
280        IF RHG75 > 100  THEN RHG75 = 100
290        IF RHB75 > 100  THEN RHB75 = 100
300        PRINT  "RH UNDER THE G50 SHADE NET  =  "  RHG50  "%"
```

```
310 PRINT "RH UNDER THE G50 SHADE NET = " RHG50 "%"
320 PRINT "RH UNDER THE G75 SHADE NET = " RHG75 "%"
330 PRINT "RH UNDER THE B50 SHADE NET = " RHB75 "%"
340 IF SRI0>500 THEN 440
350 SRIG50=SRI0*.395-7.33
360 SRIB50=SRI0*.15+12.92
365 SRIG75=SRI0*.249-1.15
370 SRIB75=SRI0*.0853-2.25
390 PRINT "SOLAR RADIATION INTENSITY UNDER THE G50 SHADE NET
    = "SRIG50"W/m}"
400 PRINT "SOLAR RADIATION INTENSITY UNDER THE B50 SHADE NET
    = "SRIB50"W/m}"
410 PRINT "SOLAR RADIATION INTENSITY UNDER THE G75 SHADE NET
    = "SRIG75"W/m}"
420 PRINT "SOLAR RADIATION INTENSITY UNDER THE B75 SHADE NET
    = "SRIB75 "W/m}"
430 GOTO 490
440 SRIG50=SRI0*.482-60.01
450 SRIB50=SRI0*.225-37.48
460 SRIG75=SRI0*.373-65.74
470 SRIB75=SRI0*.15-34.39
480 GOTO 390
490 IF LI0>15000 THEN 590
500 LIG50=LIO*.398-84.6
510 LIB50=LIO*.173-61.6
520 LIG75=LIO*.297-206.7
530 LIB75=LIO*.125-111.4
540 PRINT "LIGHT INTENSITY UNDER THE G50 SHADE NET = "LIG50 "lux"
550 PRINT "LIGHT INTENSITY UNDER THE B50 SHADE NET = "LIB50 "lux"
560 PRINT "LIGHT INTENSITY UNDER THE G75 SHADE NET = "LIG75 "lux"
570 PRINT "LIGHT INTENSITY UNDER THE B75 SHADE NET = "LIB75 "lux"
580 GOTO 640
590 LIG50=LIO*.439-4298
```

```
600     LIB50=LIO*.206-2928
610     LIG75=LIO*.311-3137
620     LIB75=LIO*.132-239961.6
630     GOTO 540
640     STOP
650     END
```

EFFECT OF DIFFERENT SHADINGS ON THE ENVIRONMENTAL PARAMETERS

By

BINDU. P. K.

ABSTRACT OF A THESIS

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ABSTRACT

Controlled environment agriculture in the form of shade houses, greenhouses, low tunnels and cloches are being practised at commercial levels in many countries. Among these, cultivation under shades is an easier method which is widely used for growing ornamental plants. Considering the scope of cultivating vegetables under shade nets, the thesis entitled 'Effect of different shadings on the environmental parameters' was undertaken. Four shade structures of size 6 m x 4 m x 2 m were constructed at the instructional farm, KCAET, Tavanur. The shade nets tested were green and black shade nests providing 50% and 75% shade respectively.

The effect of shades on the environmental parameters such as temperature, relative humidity, solar radiation intensity and light intensity were studied. These parameters were compared with those in the open space. The temperature was reduced by the shade nets, but the reduction was only in the range of 0.5 to 4°C. The temperature under the black nets was higher than that under the green nets. The relative humidity was higher under the shade nets than in the open space. Also the RH under the green nets is higher compared to that under the black nets. The solar radiation intensity and the light intensity were reduced by the nets in varying ranges. The light intensity and solar radiation intensity under the black nets were very less compared to the green nets. The equations developed give a clear idea about the variation in environmental parameters under the shade nets. The growth of tomato was better in the open space than under the shades. The growth of and yield of amaranthus was better under the G50 shade net. The growth and yield of amaranthus grown in the open space was better compared to those obtained under the G75, B50 and B75 nets.