CROP WEATHER RELATIONS ON YIELD, QUALITY AND WEED DYNAMICS OF KIRIYATH [*Andrographis paniculata* (Burm.f.) Wall. ex Nees.]

By

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(2016-11-049)

THESIS

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DECLARATION

I, Sreethu M.J (2016-11-049) hereby declare that the thesis entitled **"(Crop - weather relations on yield, quality and weed dynamics of Kiriyath (*Andrographis paniculata* (Burm.f.) Wall. ex Nees.)"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that the thesis entitled **"Crop - weather relations on yield, quality and weed dynamics of kiriyath (*Andrographis paniculata* (Burm.f.) Wall. ex Nees.)"** is a record of research work done independently by **Ms. Sreethu M.J** (2016-11-049) under my guidance and supervision and that it has not been previously formed the basis for the award of any degree, diploma, associate ship or fellowship to her.

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Introduction

1. INTRODUCTION

Use of plants as medicine is older than recorded history. The World Health Organization (WHO) estimate that 80 per cent of the population of developing countries relies on traditional medicines, mostly plant drugs, for their primary health care needs. Demand for medicinal plants is increasing in both developing and developed countries due to growing recognition of natural products having less or no side effects.

The genus, *Andrographis* consists of about 40 species, of which 19 are indigenous to India. Other prominent species are *Andrographis echioides, Andrographis serpyllifolia, Andrographis wightiana* and *Andrographis alata.* Among these, *Andrographis paniculata* and *Andrographis alata* have been reported to possess medicinal properties.

Kiriyath [*Andrographis paniculata* (Burm.f.) Wall. ex. Nees.] is an important medicinal plant belonging to the family Acanthaceae. It is commonly known as "King of Bitters", and described in *Charaka Samhita* dating to 175 BC for treatment of jaundice (Sharma, 1983). It is also known in various vernacular names such as *Kiriyattu, Kalpanath, Nilavembu, Green Chiratta, and Hempedu Bumi*. It is a traded in high volume ($\geq$ 100 tonnes/year) and prioritized by State Medicinal Plant Board, Kerala.

The plant contains four lactones, namely *A*ndrographolide, Neo andrographolide, deoxy andrographolide and dehydro andrographolide. The major active principle extracted from the leaves and stems is andrographolide which is used traditionally for the treatment of many diseases such as cancer, diabetes, high blood pressure, ulcer, leprosy, bronchitis, skin diseases, flatulence, colic, influenza, dysentery, dyspepsia and malaria (Okhuarobo *et al.*, 2014). It is commonly used as medicine in India, China and other subtropical and Southeast Asian countries.

The synthesis and accumulation of secondary metabolites responsible for medicinal property of plants are closely related to the environmental factors prevalent in growing locations. Certain secondary metabolites are synthesized only under specific environments. Sometimes, their contents significantly increase

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or decrease under specific environments. In medicinal plant cultivation, both yield and quality of produce are important. Growing conditions and time of sowing are crucial for vegetative growth and ultimate expressions of yield and quality.

Studies on growth and phytochemical responses to light intensities are useful to determine the favorable conditions for the cultivation of medicinal plants. A characteristic of *Andrographis paniculata* leaf is that it changes its color from green to red and *vice versa* from time to time when uncovered to changing force of light and shade, which shows the changes in biochemical constituents.

As in any other crop, competition from weeds adversely affects the growth and yield of kiriyath also. Mulching is a cultural method of covering the land surface with organic or inorganic materials. This practice has great influence on growth and yield of crops by way of modifying micro climate of soil and plants and also management of weeds.

As information on crop weather relations of this crop is very limited, the present experiment was formulated with the objective of assessing the effect of variations in growing conditions, time of planting and mulching on yield, quality and weed dynamics of *Andrographis paniculata.*

Review of literature

2. REVIEW OF LITERATURE

Medicinal plants are an important part of human life and use of these plants began from the start of human race. Indigenous medicinal plants and plant-derived drugs are the potential source of alternative medicines, which are extensively used to treat various health problems. Dependency on these medicinal plants varies from country to country. Burkill *et al.,* (1966) reported that about 75 - 80 per cent of the population of developing countries and about 25 per cent of that of developed countries depend either directly or indirectly on medicinal plants for the first line of treatment.

Andrographis paniculata (Burm. f.) Wall. ex Nees., is an important medicinal plant known as "King of Bitters". It belongs to the family Acanthaceae and is widely used around the world. It is an erect annual herb, found in the plains, throughout India and is generally used for the treatment of snake bite, diabetes, dysentery, fever and malaria.

The vernacular names of *Andrographis paniculata* are as follows:

Language	**Name**
Arabic	Quasabhuva
Assamese	Chiorta, Kalmegh
Bengali	Kalmegh
Chinese	ChuanXinLian
English	The Creat, King of Bitters
French	Chiretteverte, Roi des amers
Gujarati	Kariyatu
Hindi	Kirayat, Kalpanath,
Indonesian	Sambiroto, Sambiloto
Japanese	Senshinren
Kannada	Nelaberu

Language	Name
Konkani	Vhadlem Kiratyem
Malay	HempeduBumi, Sambiloto
Malayalam	Nelavepu, Kiriyattu
Marathi	Oli-kiryata, Kalpa
Panjabi	Chooraita
Tamil	Nilavembu
Telugu	Nilavembu

2.1 Habitat

Kiriyath is found in a variety of habitats including the plains, hill slopes, dry or wet lands, waste lands, farms and even on road sides. It is seen abundantly in southeastern Asia, *i.e.*, India, Sri Lanka, Pakistan, Java, Malaysia and Indonesia. However, it is cultivated extensively in India, China and Thailand, the East and West Indies, and Mauritius (Mishra *et al.*, 2007; Kanokwan and Nobuo, 2008). It occurs in wild habitat throughout the plains of India especially in Tamil Nadu, Karnataka, Maharashtra, Orissa, Uttar Pradesh and Uttarakhand. It is best suited to hot and humid climatic conditions but during monsoon season it can also be cultivated in subtropical regions (Niranjan *et al.*, 2010).

2.2 Morphology

Andrographis paniculata is an annual, branched, erect herb, with a height of 0.5-1.0 m, having a quadrangular stem with longitudinal furrows and wings on the angles of the younger parts. It prefers moist shady places, forests and wastelands (Kataky and Handique, 2010). Leaves are glabrous, opposite, simple, lanceolate, acute to acuminate at apex and green in colour with reticulate venation. Glandular and non-glandular hairs can be seen on both surfaces of the lamina Inflorescence of the plant is terminal and axillary raceme. Flowers are small, having narrow corolla tube, whitish or light pink corolla, with two stamens inserted in the throat and far exerted. Superior ovary, and style is far exerted. Capsule is erect, 1- 2 cm long, 2-5 mm wide, laterally flat with two lobes and has central depression along the separation. It contains many seeds with yellow-brown colour (Mishra *et al.*, 2007; Niranjan *et al.*, 2010).

2.3 Phytochemical constituents

The plant contains four lactones namely dehydroandroghapholide, andrographolide, neo andrographolide and deoxy andrographolide. According to Mishra *et al.* (2007), andrographolide is a diterpene lactone, colourless and crystalline in appearance, and has highly bitter taste. 3α, 14, 15, 18-tetrahydroxy-5β, 9βH, 10α-labda-8, 12-dien-16-oic acid γ-lactone is the chemical name of andrographolide. The molecular formula is $C_{20}H_{30}O_5$, while its molecular structure is shown in Figure 3.

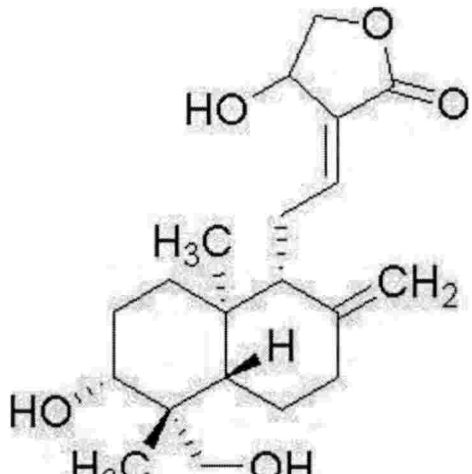

Fig.3. Molecular structure of andrographolide

The highest amount of andrographolide is present in the leaves while the seeds contain the lowest (Sharma *et al.*, 1992). Maheswari *et al.* (2000)

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observedmaximum andrographolide content at 90-120 days. Prathanturarug (2007) reported higher andrographolide content in dried leaves (12.44 to 33.52 mg g^{-1}).

2.4 Medicinal Uses and Economic importance

It has been reported that the aqueous extract of *Andrographis paniculata* significantly increases the activities of antioxidant defense enzymes such as superoxide dismutase, catalase, and glutathione-S transferase and reduced glutathione content. *Andrographis paniculata* is used for treating diseases like fever and respiratory infections, and it shows antibacterial, anti-malarial, and anti-cancerous properties. It is also used as a medicine for the treatment of hypertension and diabetes. The percentage of HIV antigen positive H9 cells were reduced when hot extract of kiriyath was used (Chang and Yeung, 1988).

It is useful in treating burning sensation, hyperdipsia, leprosy, diarrhoea, dysentery, and bronchitis (Chang, 1986). Kiriyath extracts has anti-diarrhoeal activity against *Escherchia coli* mediated diarrhoea (Gupta *et al.,* 1990). Yao *et al.* (1992) reported the anti- human immune deficiency virus activity of kiriyath when aqueous extract of the leaves were consumed. Kiriyath inhibits the multiplication of *Plasmodium berghei*. It imparts protection against malaria, because of the activation of antioxidant superoxide dismutase (Misra *et al.*, 1992). It is used for treating vitiated conditions of pitta and for the treatment of urinary tract infections (Muangman *et al.,* 1995).

Rahman *et al.* (1999) also reported the anti-malarial activity of kiriyath against *Plasmodium falciparum.* Rajagopal *et al.* (2003) reported that andrographolide inhibits the proliferation of different cell lines including leukaemia, breast cancer, lung cancer, and melanoma cells. Chewing of the fresh leaves reduces diabetes and hypertension (Verma and Vinayak, 2008). A household medicine known as 'Alui' prepared by mixing powdered cumin (*Cuminium cyminum*) and large cardamom (*Amomum subulatum*) in the juice of

Andrographis paniculata is widely utilized in West Bengal for general diseases and certain forms of dyspepsia among adults and newborn children.

Some of the herbal products in national and international markets having kiriyath as major ingredient are Andrographis 300 MG, Andrographis standardized extract, Kalmegharasa and Kalmeghasav

Indian Pharmacopoeia narrates kiriyath as an important constituent of various Ayurvedic formulations, and National Medicinal Plant board of India recommended it as one of the priority species for intensive cultivation. In Thailand, this plant was selected by the Ministry of Public Health to be included in "The National List of Essential Drugs A.D.1999" (List of Herbal Medicinal Products) (Pholphana *et al.*, 2004; Kanokwan and Nobuo, 2008; Kataky and Handique, 2010b).

Andrographis paniculata is included in the list of highly traded Indian medicinal plants (Sajwan, 2008) and occupied 17th place among the 32 prioritized medicinal plants of India with a demand of 2197.3 tons in the year 2005-2006. The total production from wild habitat is about 5,000 tonnes per year, mainly from the states of Assam, Bihar, Karnataka, Kerala, Madhya Pradesh, Andhra Pradesh, Uttar Pradesh and West Bengal.

Kiriyath has very high commercial demand which is expected to grow voluminously in the coming years. According to the National Medicinal Plant Board report (Kala *et al.*, 2006), it has an annual growth of 3.1 per cent.

2.6 Cultivation

Andrographis paniculata is cultivated as a Kharif crop in India. Hot and humid climate is required for the better growth of the plant. The best season for planting is May - June. Kiriyath is often cultivated in a wide range of soils, from loam to lateritic, with moderate fertility. Natural propagation is through shattered seeds. As roots are produced from each nodes, vegetative propagation is also possible. Seeds are to be soaked in water for 6 hours before sowing. Seeds are sown in nursery beds covered with suitable mulch and irrigated regularly till seedlings emerge (6-7 days) (NIIR, 2006). One month old seedlings are used for transplanting. Biomass yield will be maximum from 90- 100 days old plants (Pandey and Mandal, 2008). Flowering starts from third month onwards. The best harvesting time is at 50 per cent flowering or at 3 - 5 months age since the highest andrographolide content is found at this stage. Yield is about 1.25 tonnes dried plants ha^{-1}. As an entire part of plant has the active principle, whole plant is harvested, dried in shade and powdered (Niranjan *et al.*, 2010).

Kumar and Kumar (2013) conducted a study to investigate the influence of four harvesting dates (120, 135, 150 days after planting and at seed maturity) and four planting distances (30 × 15, 30 × 10, 20 × 15 and 20 × 10cm) on growth, dry herbage biomass, seed yield and quality traits of *Andrographis paniculata*. The maximum values for dry herbage biomass yield (5.14 t ha^{-1}), B:C ratio (2.59), andrographolide content (2.63%) and total yield (135.00 kg ha^{-1}) were obtained 135 days after planting with an optimum planting distance of 30 × 15cm.

Kanjilal *et al.* (2002) reported that in Assam conditions, *Andrographis paniculata* with a crop spacing of 30 cm x 30 cm and *Boerhaavia diffusa* with 45 cm row to row spacing had significant effect on herbage yield.

The growth attributes of kiriyath (plant height, number of primary branches, plant spread and dry weight of shoot) were enhanced significantly by the application of FYM 12.5 t ha^{-1} + 12.5 mg P_2O_5 kg^{-1} soil and was the best treatment combination for the highest nutrient uptake (Goel and Duhan , 2013).

In an experiment carried out to evaluate the effect of different levels of nitrogen and phosphorus on growth, yield and quality of kiriyath, Chaturvedi *et al.* (2016) reported that plant height (39.24cm.), number of leaves (414.56), plant spread (25.22 cm.), leaf area (9.40 cm^2), number of primary branches per plant (22.78), number of secondary branches (26.33), fresh herb yield per plant

(78.01g), fresh herb yield per ha (124.81q ha^{-1}), dry herb yield per plant (22.85g), dry herb yield per ha (36.55 q ha^{-1}) and maximum andrographolide content (2.25%) were higher with the treatment 100 kg N ha^{-1}+ 40 kg P ha^{-1} compared to that of control (0 kg N ha^{-1}+ 0 kg P ha^{-1}).

Abundant solar radiation and high rainfall during Kharif season cause the weeds to grow abundantly and becomes a serious threat to short statured crops like Kiriyath. Upadhyay *et al.* (2011) reported that weeds species associated with Kiriyath were *Cyperus rotundus, Cyperus iria*, *Cynodon dactylon, Ammania baccifera*, *Acalypha indica*, *Amaranthus viridis* and *Phyllanthus amara.*

According to Rao (2000), weeds accounted for 45 per cent of total annual losses of agricultural products, insects 30 per cent, diseases 20 per cent and other pests 5 per cent, and it may be more or less equal in the case of kiriyath. Kumar and Kumar (2013) found maximum fresh and dry herbage yield in weed free treatment, achieved through continuous hand weeding at different stages of crop growth.

2.7 Influence of weather parameters on crop growth and quality

Factors like climate, season, soil condition, stage of growth of plant, light intensity, and cultivation practices influence the amount of active substances present in plants. In a study conducted by Khound and Barua (2016) to assess the influence of weather parameters on flowering and fruiting in *Piper longum,* observed great influence of weather parameters on flowering and fruiting. Significant negative correlation between the number of fruiting spikes with maximum temperature, minimum temperature and rainfall was seen.

Hikosaka *et al.* (1999) reported that optimum temperature for photosynthesis is determined by the temperature during early stages of growth. When there is an increase from the optimum level of temperature the rate of photosynthesis will be affected. Chang *et al.* (2006) investigated the effect of temperature on fresh basil leaves and found that optimum temperature of 25° C produced three times higher total volatile content than plants grown with 15°C. They also observed fourfold increment in the eugenol content in warm conditions and suggested that temperature affects the growth, yield and quality of the produce. Kumar *et al.* (2011) examined the effect of temperature on seed germination parameters in Kiriyath and reported that at an optimum temperature of 25°C, 94.6 percentage germination was obtained whereas at 40° C no germination was found.

Creating moisture stress may improve the production of secondary metabolites. The active principle in kiriyath, andrographolide, was influenced by moisture regimes. The highest leaf (2.730%) and stem (1.766%) andrographolide content was recorded in moisture regime of 40 per cent potential evaporation and the lowest was recorded in 100 per cent potential evaporation (1.065% and 0.961%) in leaf and stem, respectively (Hareesh *et al.,* 2015).

Light is an important factor in plant growth. As a part of metabolism. plants synthesize certain organic compounds like alkaloids, glycosides, flavonoids, saponins, tannins, volatile oils, steroids/ terpenoids. Light intensity influences the concentration of secondary metabolites of plants. Environmental condition in which the plant is grown will influence the production of secondary metabolites.

According to Hossain *et al.* (2009) the curcumin content of turmeric increased with sunlight and gradually decreased with increase in shade. The total essential oil concentration in sage (*Salvia officinalis*) was highest (0.38 per cent on fresh weight basis) in the plants cultivated in 45 per cent full sunlight (Li *et al.,* 1996). Jaggi and Kapoor (1997) observed that Solasodine production in *Solanum laciniatum* was 10 - 12 times higher depending on light intensity. According to Jessykutty (2003), the oleoresin content of Kacholam (*Kampferia galanga*) rhizome was higher when the plants were grown at higher radiances rather than in shade. Increase in shade intensity significantly decreased the proline content in the leaves of *Alpinia calcarata, Pogostemon patchouli,* and *Kampferia galangal,* and maximum values were observed under open condition (Geetha, 2004).

Chang *et al.* (2006), reported that basil grows well in full sunlight. It can also tolerate light shade. 75 per cent shading resulted in the production of shorter plants, less number of shoots, smaller leaf area, decreased photosynthetic rate and reduced total volatile oil content. In a study conducted by Omar *et al.* (2016) in *Andrographis paniculata* to find the growth and phytochemical responses as influenced by different shade levels, increase in plant height with increased shade levels *i.e.*, plants grown under 50 per cent shade recorded tallest plants at 12 weeks after transplanting. Moreover *Andrographis paniculata* grown under full sunlight produced highest total phenolic content.

Palaniswamy (2003) found that the leaf colour changed from green to red and vice versa when exposed to varying intensities of light and shade. Leaves of kiriyath showed 35 per cent lower chlorophyll content and 30 per cent higher oxalic acid content in open condition.

2.8 Effect of time of planting on growth, herbage yield and quality in medicinal and aromatic plants

According to Sharma and Kanjilal (1999), peppermint (*Mentha piperita)* planted on 15th January recorded significantly higher plant height, number of branches, leaf stem ratio and herbage yield in a study conducted to find the effect of different planting times (January 15th, January 30th, February 14th, March 1st) on yield and quality However, the quality of oil measured by the menthol content was not affected by planting time.

In an experiment on patchouli with different planting times, Sharma and Kanjilal (2000) observed that February planted crop produced higher yield of herb and essential oil compared to March planted crop. Tiwari *et al.* (2000) examined *Plumbago zeylanica* with six planting dates (July I and III week, September I and III week and November Iand III week) and observed that maximum plant height, number of branches, root fresh and dry weight per plant and root yield July I^{st} week planted crop.

Three basil cultivars with different planting dates viz., 15^{th}, 20^{th}, 25^{th} and 30^{th} May, 4^{th} and 9^{th} June, produced higher herbage and essential oil yields from 20^{th}, 25^{th} and 30^{th} May planted plants (Zoimbra and Sas-Golak, 2002). In a study conducted by Castro *et al.* (2004) to find the effect of planting time in *Hibiscus sabdariffa,* it wasestablished that 18^{th} October planting produced significantly highest calyx fresh and dry yields out of four planting dates (18^{th} October, 15^{th} November, 18^{th} December, 15^{th} January).

Observations on the effect of plant density and sowing date on yield of basil showed higher values for plant height, above ground biomass, number of umbels per plant, number of seeds per umbel and higher seeds in 3^{rd} March planted basil plants among three sowing dates viz., 3^{rd}, 13^{th} and 23^{rd} of March (Sadeghi *et al.,* 2009).

Maheshwari *et al.* (2002) examined the response of kiriyath to different dates of planting (16^{th} July, 1^{st} August, 16^{th} August) and observed that planting on the second fortnight of July was ideal for obtaining higher herbage yield. Nemade *et al.* (2003) examined the effect of different planting dates (on 27^{th}, 29^{th}, 31^{st} and 33^{rd}meteorological weeks) on yield and quality of kiriyath and observed that early planting was significantly superior to other planting dates. In a study conducted by Singh and Singh (2006) with different dates of sowing starting from 1^{st} June to 1^{st} September at monthly intervals, it was found that sowing on 1^{st} June resulted in highest plant height, number of branches, number of leaves, and leaf area than late planting in kiriyath.

According to Sunil *et al.* (2011), among four different dates of planting (30^{th} May, 15^{th} June, 30^{th} June, 15^{th} July), crop planted on 30^{th} May had significantly higher plant height, number of branches, number of leaves, higher growth and maximum fresh and dry herbage yield under Karnataka conditions.

2.9 Effect of mulching on plant growth, herbage yield and andrographolide content

The word mulch is derived from the German word "molsch" meaning soft to decay (Jacks *et al.*, 1955). In agriculture, mulches are used for water conservation, erosion control, soil temperature modification (Brady and Weil, 1999) (*i.e.*, during hot weather period, they maintain the surface soil cooler and during cold weather keep soil warmer), weed control, soil conservation, improving soil structure, improving crop quality and yield. Increase in soil temperature and moisture due to mulching stimulates root and plant growth (Kumar *et al.,* 1990). Mulching is a good alternative to hand hoeing, as 90 per cent of mulched surfaces are weed free.

According to Bhardwaj (2013), mulch is used to cover soil surface around the plants to create optimum conditions for growth; it may include temperature moderation, salinity reduction and weed control. Based on a study conducted with and without mulch at different levels of spacing in the mid hill condition of Himachal Pradesh Panwar *et al.* (2017) reported that mulching and closer spacing had a significant effect on the growth of kiriyath. They observed that 10cm line spacing using mulch produced significantly higher germination percentage, survival percentage, number of leaves per seedling, root and shoot length, fresh root and shoot weight/seedling, dry root and shoot weight/ seedling when compared to control

Organic mulching

Organic mulches are efficient in improving soil physical properties, reducing nitrate leaching, controlling erosion, increasing biological activity, and also in nutrient cycling. (Hooks and Johnson, 2003; Muhammad *et al.* 2009). Plant and animal materials such as straw, hay, peanut hulls, leaf mould, compost, sawdust, wood chips, shavings and animal manures are used as organic mulches (Bhardwaj, 2013).

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Straw mulch is one of the earliest mulches ever used. Jodaugine *et al.* (2006) reported that straw mulch has the most reducing impact on weed emergence in June. In a study conducted by Singh *et al.* (2002) to assess the effect of organic mulch on growth, herbage yield, oil yield and quality of patchouli(*Pogostemon cablin*), it was observed that application of 5 t ha^{-1} waste material of palmarosa as organic mulch, produced maximum herbage and oil yield.

According to Patra *et al.* (1993), mulching with rice straw and citronella waste increased the herb yield by 17 and 31 per cent respectively in *Mentha arvensis*. Essential oil yield also significantly increased due to mulching. Palada *et al.* (2000) evaluated organic and synthetic mulches under drip irrigation in basil production and found that yield from plots under organic mulches were significantly higher than from synthetic mulch used plots. They also found decrease in soil temperature in the range of 1 - 6 °C in organic mulched plots.

In an experiment conducted by Duppong *et al.* (2004) to find the effect of natural mulches on crop performance, weed suppression and biochemical constituents of catnip and St. John's wart revealed a significant decrease of daily average and maximum temperature under mulched treatments particularly under straw mulch.

In a field study conducted by Ram *et al.* (2003) at Lucknow with eight treatment combinations of two variables of organic mulch (paddy straw at 7 t/ha and no mulch) and four levels of fertilizer nitrogen (0, 80, 160 and 240 kg/ha) to observe the effect of organic mulching on N-use efficiency and essential oil yield in a multi-harvested geranium crop it was found that application of paddy straw mulch increased the herb and essential oil yields in geranium by 23 per cent and 27 per cent, respectively, over the unmulched control.

Influence of organic mulching and nitrogen application on essential oil yield and nitrogen use efficiency of rosemary was studied by Singh (2012). He found that mulching with lemon grass spent material increased the herb and essential oil yields in rosemary by 16.2 per cent and 24.2 per cent, respectively, compared to that of the non-mulched control.

Polythene mulching

Plastic mulches, which are included in inorganic mulches, are used in greatest volume in commercial crop production. According to Bhardwaj (2013), plastic mulches have greater permeability to long wave radiation and this in turn increases temperature around the plants during night in winter. Black polyethylene mulches are the most widely used mulches for weed control in conventional and organic systems of crop production.

According to Clarkson (1960), soil compaction is decreased and the CO_2 level around the plant is increased when plastic mulch is used. Chen and Katan (1980) observed high water content in the top 5 cm of soil under polythene mulch. Mulches can conserve soil and moisture and reduces loss of nutrients by leaching (Ashworth and Harrison, 1983).

Use of polyethylene mulch increases the soil temperature under the plastic, which can lead to earlier production than would occur with bare soil. Galambosi and Szebeni (1992) reported that soil temperature increased by 0.2 to 0.6°C with black polythene mulch and increased yield in the medicinal plants, *Salvia officinalis, Origanum sp.,* and *Thymus sp.* Obidoska *et al.* (2004) conducted a study to find out the effect of growing factors on the yield of seeds of ashwagandha (*Withania somnifera*) cultivated in Polish climatic conditions. The experiments were conducted in experimental greenhouse in the years 1998 - 2000. They found that total number of seeds per m^2 and the percentage of seeds capable of germinating were significantly increased by mulching with black polythene.

Experiments on medicinal herbs indicated that in rosemary, plants grown on bare ground without herbicide treatments were less vigorous than grown on plastic mulches with herbicide (Ricotta and Masiunas, 1991). Another study carried out by Giri *et al.* (2016) in sweet basil proved that for an effective weed management with maximum oil and herbage yield, use of polythene mulch is the best practice. They obtained a significant difference in the fresh, shade dried and oven dried herbage yield in various weed management practices viz., manual weeding, straw mulching, polythene mulching, and pre emergence application of pendimethalin, and recorded maximum fresh herbage yield of 35.01 t ha^{-1} from weed free treatment, followed by polythene mulched treatment with 34.53 t ha^{-1}. The least fresh herbage yield was obtained from the weedy check.

Gunasekaran *et al.* (2014) evaluated the effect of mulching on weed control and tuber yield of medicinal coleus (*Coleus forskholli*) under different mulching materials and found the lowest weed density, and weed biomass from black polythene mulched treatments. Among the different tuber characters examined except forskholin content, black polythene mulch had highly significant effect on the number of tubers per plant, tuber length, girth, volume and fresh weight.

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Materials & Methods

3. MATERIALS AND METHODS

A field experiment entitled, "Crop - weather relations on yield, quality and weed dynamics of kiriyath (*Andrographis paniculata* (Burm.f.) Wall. ex Nees.)" was conducted during May - Jan 2017 at the Agronomy Farm, Department of Agronomy, College of Horticulture, Vellanikkara. The details of the materials used and methods adopted for experimentation are presented in this chapter.

3.1 Geographical specification of the experimental site

Location

The experiment was conducted at the Agronomy Farm, Department of Agronomy, College of Horticulture, Vellanikkara, Thrissur, Kerala. The field is situated at 13° 32'N latitude and 76° 26'E longitude, at an altitude of 40 m above mean sea level.

Climate and weather conditions

The area enjoys a typical humid tropical climate. The mean weekly averages of important meteorological parameters observed during the experimental period are presented in Appendix 1 and illustrated graphically in Fig. 1.

Soil

The texture of the experimental site is sandy clay loam and is acidic in reaction with a pH of 4.65. The physic - chemical properties are depicted in Table 1.

Season

The experiment was conducted during the period from May - January 2017.

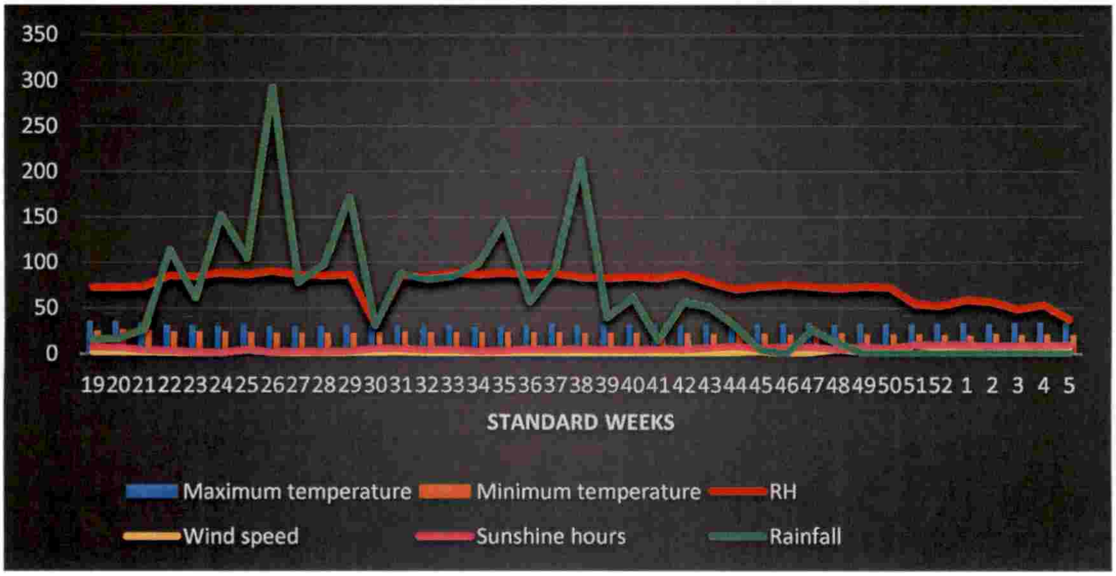

Fig. 1 Mean weekly weather data of atmospheric temperature, RH, and rainfall during crop period

Table 1. Physico - chemical properties of soil

Particulars	Value	Method used
1. Physical properties **Particle size composition**		
Coarse sand (%)	31.90	Robinson international pipette method (Piper, 1942)
Fine sand (%)	27.30	
Silt (%)	18.64	

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Clay (%)	22.16	
2. Chemical properties		
pH	4.65	1: 2.5 soil water suspension (Jackson, 1958)
Organic carbon (%)	1.13	Walkley and Black method (Jackson, 1958)
Available N (kg ha^{-1})	189.00	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg ha^{-1})	10.08	Ascorbic acid reduced molybdo phosphoric blue colour method (Bray and Kurtz, 1945; Watanabe and Olsen, 1965)
Available K (kg ha^{-1})	259.64	Neutral normal ammonium acetate extraction and estimation using flame photometry (Jackson, 1958)

Crop

A local cultivar of kiriyath was used for the experiment. It is an erect annual herb with quadrangular stem, simple lanceolate leaves with acute apex and base. Seeds are numerous, tapering, and yellow brown in colour.

Cropping history of the experimental site

The experimental area had been under cultivation with okra during the previous year.

3.2 Experimental details

The experiment was laid out in Randomized Block Design with factorial concept (FRBD) with 24 treatment combinations and three replications. The plot size was 3 m x 3 m with plant spacing of 30 cm x 15 cm. The treatment details are given in Table 2.

Treatments

Factor A: Growing condition

1. Open
2. 50% Shade

Factor B: Planting dates

1. May 15th
2. June 15th
3. July 15th
4. August 15th

Factor C: Mulching

1. No mulching
2. Paddy straw mulch @ 5t/ha
3. Mulching with polythene sheet (30 micron silver top black bottom polythene)

Table 2. Details of treatments

Sl.No	Treatments combination	Treatment details
1	$A_1B_1C_1$	Open + May 15^{th} + No mulching
2	$A_1B_1C_2$	Open + May 15^{th} + Paddy straw mulch
3	$A1B_1C_3$	Open + May 15^{th} + Mulching with polythene sheet
4	$A_1B_2C_1$	Open + June 15^{th} + No mulching
5	$A_1B_2C_2$	Open + June 15^{th} + Paddy straw mulch
6	$A_1B_2C_3$	Open + June 15^{th} + Mulching with polythene sheet
7	$A_1B_3C_1$	Open + July 15^{th} + No mulching
8	$A_1B_3C_2$	Open + July 15^{th} + Paddy straw mulch
9	$A_1B_3C_3$	Open + July 15^{th} + Mulching with polythene sheet
10	$A_1B_4C_1$	Open + August 15^{th} + No mulching
11	$A_1B_4C_2$	Open + August 15^{th} + Paddy straw mulch
12	$A_1B_4C_3$	Open + August 15^{th} + Mulching with polythene sheet
13	$A_2B_1C_1$	50% Shade + May 15^{th} + No mulching
14	$A_2B_1C_2$	50% Shade +May 15^{th} + Paddy straw mulch
15	$A_2B_1C_3$	50% Shade +May 15^{th} + Mulching with polythene sheet
16	$A_2B_2C_1$	50% Shade +June 15^{th} + No mulching
17	$A_2B_2C_2$	50% Shade +June 15^{th} + Paddy straw mulch
18	$A_2B_2C_3$	50% Shade +June 15^{th} + Mulching with polythene sheet
19	$A_2B_3C_1$	50% Shade +July 15^{th} + No mulching
20	$A_2B_3C_2$	50% Shade +July 15^{th} + Paddy straw mulch
21	$A_2B_3C_3$	50% Shade +July 15^{th} + Mulching with polythene sheet
22	$A_2B_4C_1$	50% Shade +August 15^{th} + No mulching
23	$A_2B_4C_2$	50% Shade +August 15^{th} + Paddy straw mulch
24	$A_2B_4C_3$	50% Shade + August 15^{th} + Mulching with polythene sheet

Layout

The layout plan of the experimental field is given in Fig.2.

Land preparation and sowing

The seeds procured from AICRP on Medicinal and Aromatic plants were pre soaked and sown in pro trays filled with coirpith compost, and watered. The experimental field was ploughed thoroughly with disc plough and brought to a fine tilth by working with a cultivator. Weeds and stubbles were removed and plots were laid out as per the layout plan (Fig.2 and Plate1.). Beds were prepared and as per the treatments, mulch materials were spread uniformly on individual plots. Planting in polythene mulched plots was done by making circular holes of 5 cm diameter, at a spacing of 30 cm x 15 cm.

Planting

One month old healthy, uniform sized seedlings were selected and transplanted in the main field as per planting treatments at a spacing of 30 cm between rows and 15 cm between the plants and the plots were irrigated immediately.

Manures and fertilizers

FYM @ 5t/ha was applied as basal and N: P_2O_5: K_2O was applied @ 80:40:20 kg/ha. Full quantity of P was applied as basal and N and K in two equal splits at 30 DAP and 60 DAP.

Irrigation

Hose irrigation was done on the beds at 10 mm depth once in 3 days.

Fig. 2. Layout of experimental field

N

OPEN									50 % SHADE								
R1			**R2**			**R3**			**R1**			**R2**			**R3**		
B_1C_1	B_1C_2	B_3C_2	B_2C_1	B_1C_2	B_1C_3	B_1C_1	B_3C_2	B_1C_3	B_1C_3	B_1C_2	B_1C_1	B_1C_1	B_2C_1	B_1C_3	B_1C_3	B_1C_2	B_1C_1
B_4C_3	B_2C_2	B_3C_1	B_1C_1	B_2C_2	B_4C_2	B_4C_1	B_3C_3	B_4C_3	B_2C_1	B_3C_3	B_2C_3	B_1C_2	B_2C_2	B_4C_3	B_2C_1	B_3C_3	B_2C_3
B_2C_3	B_1C_3	B_3C_3	B_3C_2	B_3C_1	B_3C_3	B_3C_1	B_1C_2	B_2C_2	B_3C_1	B_4C_1	B_2C_2	B_3C_3	B_3C_2	B_3C_1	B_4C_2	B_3C_2	B_2C_2
B_4C_1	B_4C_2	B_2C_1	B_4C_1	B_2C_3	B_4C_3	B_4C_2	B_2C_1	B_2C_3	B_3C_2	B_4C_2	B_4C_3	B_4C_1	B_4C_2	B_2C_3	B_4C_1	B_3C_1	B_4C_3

3m

BI- May 15

B2- June 15

B3- July 15

B4- August 15

C1- No mulch

C2- Paddy straw mulch

C3- Black polythene mulch

Weed management

Weed management was done as per the treatments. Hand weeding were done at 30 and 60 DAP in the plots without any mulching.

Plant protection

No serious disease or pest attack was observed in the experimental area during the cropping period.

Harvesting

The harvesting of crop was carried out after five months of planting at flowering stage by uprooting plants.

3.3 Observations recorded

3.3.1 Soil analysis

The pH, organic carbon and major nutrients were estimated before and after the experiment. Soil samples were collected, dried, powdered and passed through 0.5 mm sieve and used for analyzing the organic carbon content, and samples passed through 2 mm sieve were used for analyzing major nutrients viz., available N, available P and available K using standard procedures detailed in Table 1. The soil pH was analyzed in a soil: water suspension of 1: 2.5.

3.3.2 Weather observations

1. Maximum and minimum temperatures (°C)
2. Rainfall (mm)
3. Relative humidity (%)
4. Bright sunshine hours
5. Wind speed (km hr^{-1})

3.3.3 Microclimate studies

Soil temperature

Soil temperature at 10 cm depth was recorded daily with the help of a soil thermometer and the mean was worked out.

Soil moisture content

Soil moisture content at 0-15 cm depth was determined at fortnightly intervals by thermo gravimetric method using the formula

$$Pw = \frac{Wm\text{-}Wd \times 100}{Wd}$$

Pw = Percentage of soil moisture by weight Wm = Weight of moist sample

Wd = Weight of oven dry sample

3.3.4 Biometric observations

Five plants per treatment per replication were randomly selected and tagged and the following observations were recorded:

1. Plant height at 30 DAP, 60 DAP and at harvest
2. No. of branches at 30 DAP, 60 DAP and at harvest
3. Days to first flowering
4. Biomass yield at 30 DAP, 60 DAP and at harvest
5. Total biomass production at harvest (kg ha^{-1})

Plant height

Plant height was measured from the ground level to the growing tip of plants at 30 DAP, 60 DAP and at harvest and averages were expressed in cm.

Number of branches per plant

Branches arising from main stem of the tagged plants were counted at 30 DAP, 60 DAP and at harvest and the average number of branches per plant was worked out.

Fresh weight

Randomly selected plants in each treatment and replication were uprooted at 30 DAP, 60 DAP and at harvest and their fresh weight was recorded and average fresh weight per plant was calculated and expressed in grams.

Dry weight

Plants used for fresh weight determination at 30 DAP, 60 DAP and at harvest were first shade dried and then dried in hot air oven till they attained constant weight. Sample dry weights were recorded and expressed in grams.

3.3.5. Physiological, chemical and biochemical observations

1. Chlorophyll content at 30 DAP, 60 DAP and at harvest
2. Crop growth rate at 30 DAP, 60 DAP and at harvest
3. Relative growth rate at 30 DAP, 60 DAP and at harvest
4. Andrographolide content at harvest

Chlorophyll content

Chlorophyll content in the leaves was estimated at 30DAP, 60 DAP and at harvest using Dimethyl sulphoxide (DMSO) Chlorophyll extraction technique of Hiscox and Israelstam (1979).

Crop growth rate (CGR)

Crop growth rate indicates at what rate the crop is growing *i.e.* whether the crop is growing at a faster rate or slower rate than normal. It is expressed as gram of dry matter produced per day. Crop growth rate was calculated by the following formula and expressed as g $day^{-1}m^{-2}$ (Watson, 1952).

$$CGR\ (g / day / m^2) = \frac{w_2 - w_1}{t_2 - t_1}$$

Where w_1 and w_2 are dry weights of plants at time t_1 and t_2, respectively

Relative growth rate (RGR)

This parameter indicates rate of growth per unit dry matter. It is expressed as gram of dry matter produced by a gram of existing dry matter in a day. Relative growth rate was calculated by the following formula (Blackman, 1919) and expressed as g g^{-1} day^{-1}:

$$RGR\ (g / g / day) = \frac{\log_e w_2 - \log_e w_1}{t_2 - t_1}$$

Where w_1 and w_2 are dry weights of plants at time t_1 and t_2, respectively

Andrographolide content

High performance thin layer chromatographic (HPTLC) methods for quantitative determination of andrographolide were followed. (Vijaykumar *et al.*, 2007). One gram of powdered plant material was refluxed for one hour with 50 ml methanol on a water bath. It was filtered and again subjected for refluxing for another two cycles of one hour each using 50 ml methanol. The combined filtrates were evaporated under vacuum to dryness. The residue was dissolved in methanol (25 ml) and filtered through a 0.45 μm filter into HPTLC vials.

3.3.6. Observation on weeds

1. Weed count at 30 DAP and 60 DAP
2. Weed dry weight at 30 DAP and 60 DAP
3. Weed control efficiency
4. Weed index

Weed count

Weed count was recorded species wise using a 50 cm x 50 cm (0.25 m^2) quadrat. The observations were recorded at 30 DAS, 60 DAS and at harvest by placing the quadrat in each plot at random. The count was expressed in number m^{-2}.

Dry matter content of weeds

Weeds collected from the quadrat were uprooted, cleaned, air dried and oven dried at 80 ± 5°C and dry weight was recorded in g m^{-2}.

Weed control efficiency

The weed control efficiency was worked out using the formula suggested by Mani *et al.* (1973).

$$WCE = \frac{\text{weed dry weight in unweeded plot - weed dry weight in treated plot}}{\text{Weed dry weight in unweeded plot}} \times 100$$

Weed index

Weed index was calculated using the formula suggested by Gill and Vijaykumar (1969).

$$WI = \frac{X-Y}{Y} X\ 100$$

X = Yield from treatment with least weeds

Y = Yield from treated plot

3.3.7 Economic analysis

The Benefit: Cost ratio was worked out using the formula given below:

$$BCR = \frac{\text{Gross returns}}{\text{Cost of cultivation}}$$

3.3.8 Statistical analysis

The data collected were subjected to analysis of variance using the statistical package 'OP Stat' (Sheoran *et al.*, 1998). The data on weed density and weed biomass which showed wide variation were subjected to square root transformation ($\sqrt{x}$ +0.5) to make the analysis of variance valid (Gomez and Gomez, 1984).

Plate 1. General field view

Open **Shade**

30 DAP

30 DAP

60 DAP

60 DAP

Plate 2. Effect of treatments on plant growth at different stages

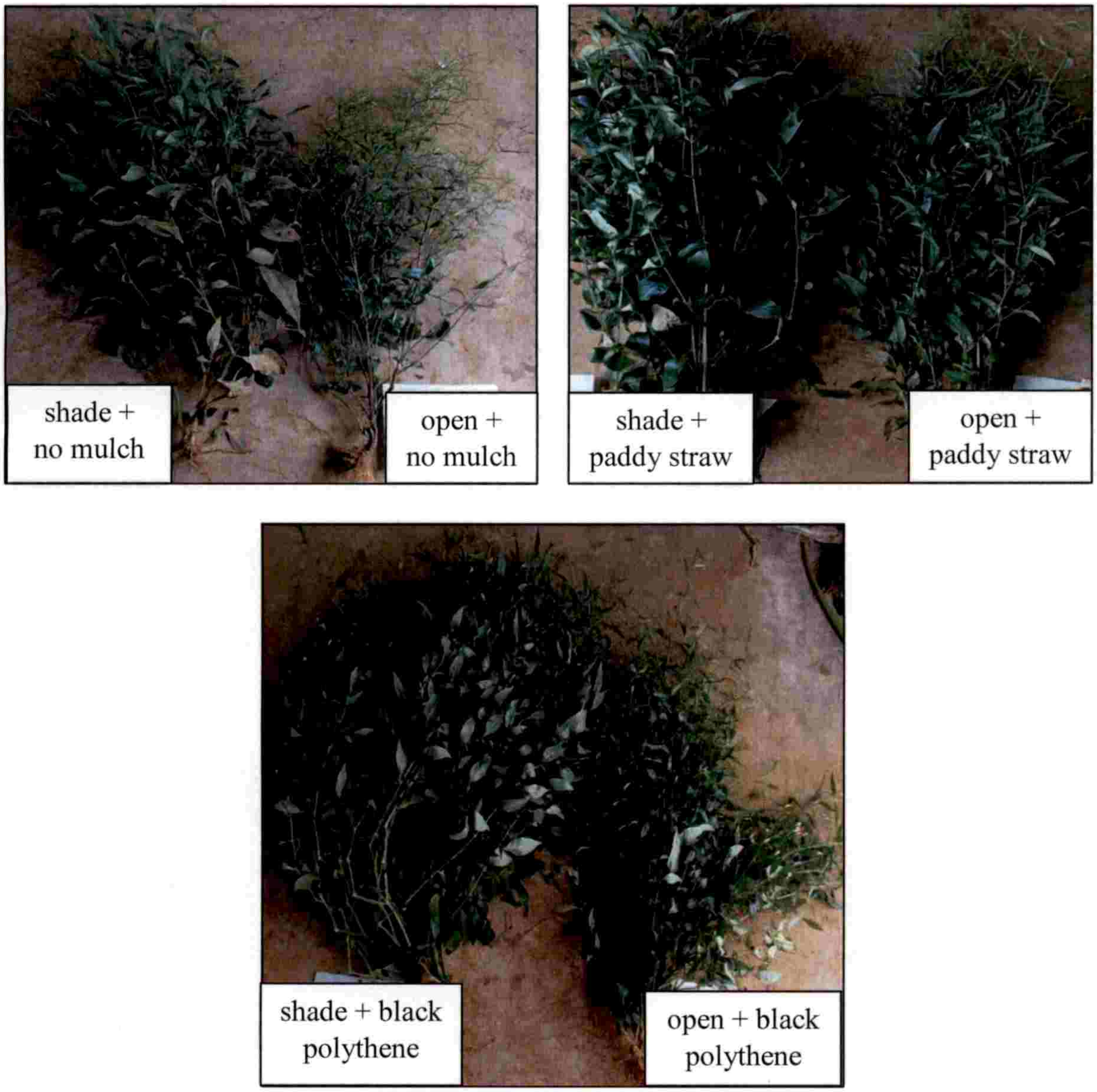

Plate 3. Growth of May planted crop under different growing condition and mulching

Results

4. RESULT

4.1. Direct effect of treatments

4.1.1. Biometric observations

Plant height at 30, 60 DAP and at harvest

Growing condition significantly influenced the plant height of *Andrographis paniculata* at 30 DAP (Table 3). The crop planted under 50 per cent shaded condition recorded the greatest plant height of 7 cm whereas, plant height under open condition was 4.46 cm. However, planting dates did not show any significant influence on plant height at this stage. Plants under different mulch materials showed significant variation with respect to plant height at 30 DAP. The highest plant height (6.53 cm) was recorded in mulching with black polythene sheet whereas minimum plant height (4.95 cm) was in treatment without any mulch.

At 60 DAP, growing condition, different dates of planting and mulching produced significant difference in plant height. The greatest plant height (26.83 cm) was observed in plants under shaded condition. Among planting dates, 15th July planting recorded the tallest (28.96 cm) plants and 15th May planting recorded shortest plants (10.26 cm). Among different mulches, mulching with black polythene sheet recorded taller plants (24.52 cm). Shortest plants were noted in paddy straw mulching.

Similar trends were noticed with respect to plant height at harvest also. At harvest, taller plants were noticed under shade (81.36 cm), 15th July planting (79.75 cm) and with black polythene mulch (71.08 cm).

No. of branches per plant at 30 DAP, 60 DAP and at harvest

No branches were observed at 30 DAP. At 60 DAP, growing condition had no significant effect on number of branches. Crops planted in June recorded higher number of branches (7.11) which was on par with August and July planting (Table 3). Among mulches, black polythene mulching resulted in the higher number of branches (7.45). Lower number of branches were recorded for treatment without any mulch (5.87).

At harvest, crops grown under shade produced the highest number of branches (22.86). Different planting dates showed significant influence on number of branches. Planting on 15th May recorded greatest number of branches (22.44). Mulching with black polythene sheet continued its superiority in number of branches at harvest (22.78) too. Lower number of branches were recorded in the treatment without any mulch. Muhammed (2015) reported improvement in height and number of branches of plants grown under polythene mulches.

Days to first flowering

The number of days to first flowering in shaded condition was 116 days whereas in open condition it was 109 days. Different dates of planting exhibited significant influence on number of days to first flowering. Crops planted on 15th July took more number of days (118) for flowering, followed by planting in 15th August (115 days). Planting on 15th May and 15th June took lower number of days for flowering (108 and 109 days). Mulching did not exhibit significant effect on days to first flowering (Table 3).

Fresh biomass yield at 30, 60 DAP and at harvest

The influence of different growing condition, dates of planting and mulching on biomass yield at different growth stages are furnished in Table 4.

Table 3. Effect of treatments on plant height, number of branches and days to first flowering in kiriyath at different growth stages

Treatments	Plant height (cm)			No. of branches		Days to first flowering
	At 30 DAP	At 60 DAP	At harvest	At 60 DAP	At harvest	
Growing condition						
Open	4.46	16.05	57.22	6.58	19.62	109
50% Shade	7.00	26.83	81.36	6.51	22.86	116
CD (0.05)	0.37	0.57	1.80	NS	0.67	1.20
Planting Date						
15-May	5.84	10.26	66.64	5.44	22.44	108
15-Jun	5.83	19.55	64.77	7.11	21.15	109
15-Jul	5.67	28.96	79.75	6.84	20.46	118
15-Aug	5.59	27.00	65.99	6.79	20.91	115
CD (0.05)	NS	0.81	2.54	0.36	0.95	1.69
Mulching						
No mulch	4.95	19.77	68.97	5.87	20.26	113
Paddy straw mulch	5.70	20.04	67.81	6.32	20.68	112
Black polythene mulch	6.53	24.52	71.08	7.45	22.78	113
CD (0.05)	0.46	0.70	2.20	0.31	0.82	NS

Table 4. Effects of treatments on fresh biomass yield and total yield of kiriyath

Treatments	Biomass yield (g $plant^{-1}$)			Total yield (kg ha^{-1})
	At 30 DAP	At 60 DAP	At harvest	At harvest
Growing condition				
Open	1.11	10.39	97.14	8,038
50% Shade	2.06	13.63	116.32	10,019
CD (0.05)	0.10	0.81	4.52	466.97
Planting Date				
15-May	1.56	12.46	143.93	12,873
15-Jun	1.64	14.33	110.52	9,420
15-Jul	1.59	10.67	76.07	5,860
15-Aug	1.53	10.60	96.40	7,961
CD (0.05)	NS	1.15	6.39	660.39
Mulching				
No mulch	1.36	8.83	83.77	6,656
Paddy straw mulch	1.41	10.51	98.53	8,182
Black polythene mulch	1.98	16.70	137.89	12,249
CD (0.05)	0.13	0.99	5.53	571.92

Crops planted in shade recorded significantly higher dry weight per plant (2.06 g plant^{-1}) at 30 DAP. Planting dates did not exhibit significant influence on fresh biomass yield of kiriyath at this stage. Among different mulches tried, the highest biomass yield (1.98 g plant^{-1}) was recorded in the treatment with black polythene mulch.

At 60 DAP also, shaded condition continued its superiority with respect to plant biomass yield (13.63 g plant^{-1}). Planting on 15th June resulted in higher biomass yield (14.33g plant^{-1}) followed by planting on 15th May (12.46 g plant^{-1}). Mulching with black polythene sheet recorded highest fresh biomass yield (16.70 g plant^{-1}).

At harvest stage, plants grown under 50 per cent shade recorded higher fresh biomass yield of 116.32 g plant^{-1}. Among different planting dates, planting in May resulted in higher biomass yield (143.93 g plant^{-1}) and planting in July recorded lower (76.07 g plant^{-1}). Plants mulched with black polythene sheet recorded higher biomass yield of 137.89g plant^{-1}. Plants without any mulch recorded lower biomass yield (83.77 g plant^{-1}).

Total yield

Treatments significantly influenced the total yield of kiriyath (Table 4). Yield was higher (10,019 kg ha^{-1}) in crop grown under 50 per cent shaded condition compared to those under open condition (8038 kg ha^{-1}).Among the different dates of planting, planting on 15th May resulted in the highest yield of 12873 kg ha^{-1}. Planting on 15th June was the next best treatment with respect to total yield (9420 kg ha^{-1}). Planting on 15th July resulted in the lowest yield (5860 kg ha^{-1}). Mulching also significantly influenced the yield of kiriyath, with highest yield under black polythene mulch (12249 kg ha^{-1}). The yield from plots with paddy straw mulch and no mulch were 8182 and 6656 kg ha^{-1} respectively.

4.1.2. Soil analysis

Soil pH

Direct effect of treatments on soil pH is depicted in Table 5. The soil was acidic in nature with a mean pH of 4.65 but after the experiment there was an increasing trend in soil pH as compared to pre experimental soil. The differences in soil pH among the treatments were found non significant.

Organic carbon

Data on the effect of growing condition, planting dates and mulching did not show any significant effect on organic carbon content of soil (Table 5).

Available nitrogen

The direct effect of growing condition, planting dates and mulching on the available nitrogen was non significant (Table 5).

Available phosphorus

Data given in Table 5 showed that main effect of growing condition, planting date and mulching on available phosphorus content in soil was non significant

Available potassium

Growing condition, planting date and mulching significantly influenced the available soil K content. K content was higher than 50 per cent shade recorded from open condition (168.40 kg ha^{-1}). Among the different dates of planting August planted plots recorded higher K content (176.58 kg ha^{-1}) whereas lower K content was noticed in May planted plots (158.52 kg ha^{-1}). Paddy straw mulched plots was having higher K content (188.08 kg ha^{-1}) whereas lower content was in plots without any mulch (146.02 kg ha^{-1}).

Table 5. Effects of treatments on soil pH, organic carbon and available N, P and K after harvest of kiriyath

Treatments	pH	Organic carbon (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
Growing condition					
Open	5.39	1.95	244.60	10.12	168.40
50% Shade	5.26	2.09	247.64	10.28	163.42
CD (0.05)	NS	NS	NS	NS	0.20
Planting Date					
15-May	5.37	2.05	247.40	10.27	158.52
15-Jun	5.44	2.10	244.86	10.22	164.82
15-Jul	5.28	2.00	247.34	10.36	163.72
15-Aug	5.22	1.92	244.86	9.95	176.58
CD (0.05)	NS	NS	NS	NS	0.28
Mulching					
No mulch	5.39	2.06	246.15	10.22	146.02
Paddy straw mulch	5.32	1.90	245.66	10.20	188.08
Black polythene mulch	5.26	2.09	246.48	10.18	163.62
CD (0.05)	NS	NS	NS	NS	0.24
Pre experimental	4.65	1.13	189.00	10.08	259.84

4.1.3. Micrometeorological observations

Soil temperature at 10 cm depth

Main effects of all the treatments had significant effects on soil temperature. In general, throughout the growing period higher soil temperature was observed in open condition compared to that of shaded condition. Higher temperatures were recorded in open condition on 1^{st} and 4^{th} week (28.1 °C) respectively and were on par with 7^{th} week (28 °C). Lower temperatures were recorded in shaded condition on 9^{th} and 16^{th} week (25.5 °C).

Soil temperature was not affected by different dates of planting in most of the plantings except a few. Soil temperature was higher under black polythene sheet mulch throughout the growing period whereas paddy straw mulch and no mulch condition showed almost similar soil temperatures. During initial stages of the crop, lower temperature (25.7°C) was recorded on the 5^{th} week under both no mulch and paddy straw mulch. During the flowering stage lower soil temperatures were observed on 16^{th} week (25.8 °C) under both no mulch and paddy straw mulch, and higher temperatureswere recorded under black polythene sheet in 16^{th} week.

Soil moisture at 15 cm depth

Data regarding soil moisture content at different days after planting are given in Table 7. Growing condition had significant influence on soil moisture content throughout the growing period. In general, higher soil moisture content was observed in shaded condition than open condition with the highest moisture content (57.90 %) recorded at 42 DAP and lowest (12.66 %) observed at 116 DAP in open condition. Different planting dates showed significant influence on soil moisture content. Higher soil moisture contents were recorded at 42 DAP of May planted plot, 60 DAP of July planting and 42 DAP of August planted plots whereas lower soil moisture content was noticed in 130 DAP of August planted plots. As far as mulching is concerned, mulched

Table 6. Effect of treatments on soil temperature at 10 cm depth

Treatments	Soil temperature (°C)																			
	Weeks																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Growing condition																				
Open	28.1	27.5	27.7	28.1	27.1	27.7	28.0	27.9	27.4	27.8	27.9	27.9	27.3	27.6	27.7	27.1	27.2	26.9	27.3	27.1
50% Shade	26.2	25.9	26.2	26.0	25.7	25.8	26.2	25.9	25.5	26.0	25.8	25.8	25.7	25.9	25.9	25.5	25.6	25.9	26.2	25.9
CD (0.05)	0.04	0.04	0.09	0.05	0.04	0.04	0.04	0.07	0.04	0.03	0.17	0.01	0.02	0.02	0.02	0.06	0.01	0.01	0.02	0.02
Planting Date																				
15-May	27.9	26.5	25.5	27.4	26.4	27.0	26.9	26.4	26.8	27.9	27.3	26.8	26.8	27.4	27.3	25.9	26.7	25.9	26.7	26.8
15-Jun	27.5	26.4	27.0	26.8	26.4	26.8	27.9	27.3	26.7	26.8	27.4	27.3	25.9	26.7	26.2	26.7	26.6	26.6	26.6	26.7
15-Jul	26.4	26.8	27.9	27.3	26.7	26.8	27.4	27.2	25.8	26.6	26.1	26.7	26.6	26.2	26.9	26.3	26.5	26.4	26.3	26.1
15-Aug	26.8	27.1	27.4	26.8	26.2	26.4	26.3	26.6	26.3	26.4	26.7	26.5	26.8	26.6	26.9	26.2	26.0	26.7	27.4	26.4
CD (0.05)	NS	NS	0.12	0.06	NS	NS	NS	NS	NS	NS	NS	NS	0.02	NS	NS	NS	NS	0.01	NS	NS
Mulching																				
No mulch	26.5	26.0	26.5	26.4	25.7	26.1	26.4	26.2	25.7	26.2	26.2	26.1	25.8	26.0	26.1	25.6	25.8	25.7	26.1	25.8
Paddy straw mulch	26.6	26.0	26.5	26.4	25.7	26.1	26.4	26.2	25.7	26.2	26.2	26.1	25.8	26.0	26.1	25.6	25.8	25.8	26.1	25.8
Black polythene mulch	28.4	28.1	27.8	28.4	27.8	28.1	28.5	28.2	27.9	28.3	28.2	28.2	27.9	28.1	28.3	27.7	27.8	27.7	27.9	27.8
CD (0.05)	0.05	0.04	0.11	0.06	0.05	0.05	0.05	0.09	0.05	0.04	0.21	0.02	0.02	0.02	0.02	0.08	0.02	0.01	0.02	0.02

Table 7. Effect of treatments on soil moisture at 15 cm depth

Treatments	Soil moisture (%)									
	14 DAP	28 DAP	42 DAP	56 DAP	60 DAP	74 DAP	88 DAP	102 DAP	116 DAP	130 DAP
Growing condition										
Open	14.78	14.68	57.59	13.62	35.88	14.18	13.64	13.14	12.66	12.72
50% Shade	16.83	16.05	57.90	14.62	36.95	15.25	14.61	14.51	13.93	13.76
CD (0.05)	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.08
Planting Date										
15-May	14.45	14.47	100	13.73	16.97	13.66	13.49	13.92	14.31	13.82
15-Jun	15.79	16.21	16.80	13.48	14.25	14.84	15.98	13.94	13.58	13.92
15-Jul	16.99	16.60	14.14	14.86	100	16.26	13.82	13.55	13.12	13.23
15-Aug	15.99	14.18	100	14.42	14.42	14.09	13.21	13.89	12.19	11.99
CD (0.05)	0.02	0.01	0.03	0.02	0.02	0.01	0.02	0.02	0.02	0.12
Mulching										
No mulch	14.63	14.47	56.81	13.01	35.51	13.41	12.59	12.99	12.34	12.28
Paddy straw mulch	15.59	15.32	57.85	14.15	36.35	14.58	14.08	13.41	13.08	12.94
Black polythene mulch	17.20	16.30	58.58	15.22	37.39	16.15	15.71	15.08	14.48	14.50
CD (0.05)	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.10

plots showed higher soil moisture content than no mulch condition. Within the mulches, under black polythene mulch, higher soil moisture was observed. Higher value (58.58 %) was found at 42 DAP with black polythene mulch and lower soil moisture (12.28 %) in no mulch condition at 130 DAP.

4.1.4. Physiological, chemical and biochemical observations

Total chlorophyll content at 30 DAP, 60 DAP and harvest

Data on the influence of different growing conditions, dates of planting and mulching on total chlorophyll content at 30 DAP, 60 DAP and at harvest, and andrographolide content at harvest are furnished in Table 8.

At 30 DAP, there was no significant difference in total chlorophyll content due to growing condition. Planting date and mulching significantly influenced the total chlorophyll content at 30 DAP, 60 DAP and at harvest. At 30 DAP, total chlorophyll content was significantly higher in the crop planted in August (1.32 mg g^{-1}) and minimum was recorded from the crop planted in July (0.77 mg g^{-1}). Crops planted without any mulch recorded higher total chlorophyll content (1.18 mg g^{-1}) whereas crops mulched with paddy straw possessed lower chlorophyll content (0.82 mg g^{-1}).

At 60DAP, total chlorophyll content was higher in crops planted in 50 per cent shaded condition (1.72 mg g^{-1}). Higher total chlorophyll content was recorded in June planting (1.99 mg g^{-1}) and lowest chlorophyll content (1.36 mg g^{-1}) was recorded from the crop planted in the month of July. Mulching with black polythene sheet recorded higher chlorophyll content (1.73 mg g^{-1}) and was on par with no mulch condition (1.72 mg g^{-1}). Crops planted with paddy straw mulching recorded lowest chlorophyll content (1.47 mg g^{-1}).

At harvest, crop planted in 50 per cent shaded condition recorded highest chlorophyll content (2.23 mg g^{-1}) whereas open condition recorded lower chlorophyll content (1.61 mg g^{-1}). Crop planted in May has higher chlorophyll content of 2.22 mg $g^{-1}$and minimum chlorophyll content was recorded in August planting (1.72 mg g^{-1}). In case of mulching, crops provided with paddy straw mulching recorded higher chlorophyll content (2.08 mg g^{-1}) and no mulch condition recorded lower chlorophyll content (1.71 mg g^{-1}).

Andrographolide content (%)

The results indicated that all the treatments had significant effect on andrographolide content at harvest. Andrographolide is one of the most important alkaloids which was found in highest content (1.05%) in 50 per cent shaded condition whereas open condition recorded only 0.96 per cent. Comparing different dates of planting, andrographolide content was found maximum (1.04%) in August planting and minimum was recorded in June planting. Among different mulches, the highest andrographolide value (1.05%) was with paddy straw mulch and minimum was recorded in no mulch condition (0.97%) which was on par with black polythene mulch.

Crop growth rate

Crop growth rate (CGR) at 30 to 60 DAP was unaffected by growing condition. However planting dates and mulching had influenced CGR at 30 to 60 DAP with higher growth rates in June planting (2.09 g m^{-2} day^{-1}) and under black polythene mulching (2.11 g m^{-2} day^{-1}). Lower CGR was recorded in August planting (1.10 g m^{-2} day^{-1}) and crops without mulching (1.14 g m^{-2} day^{-1}).

At 60 DAP to harvest period also, growing condition had no significant influence on CGR whereas, planting dates and mulching influenced it significantly. At this stage, higher CGR was recorded in June planting (10.1 g m^{-2} day^{-1}) and black polythene mulching (8.99 g $m^{-2}day^{-1}$). July planting (5.86 $gm^{-2}day^{-1}$) and paddy straw mulching (7.13 g m^{-2} day^{-1}) recorded lower CGR value.

Relative growth rate

Relative growth rate was significantly influenced by growing condition, planting dates and mulching (Table 9). At 30 DAP to 60 DAP, high RGR was recorded in open condition (0.076 g g^{-1} day^{-1}), June planting (0.079 g g^{-1} day^{-1})

and black polythene mulch (0.074 g g^{-1} day^{-1}). At 60 DAP to harvest, RGR was unaffected by growing condition and planting dates. Mulching significantly influenced the relative growth rate. No mulch condition recorded higher RGR (0.033 g g^{-1} day^{-1}) and lower RGR was recorded in black polythene mulch (0.029 g g^{-1} day^{-1}).

4.1.5. Observations on weeds

Weed density

Data on direct effect of treatments on weed density, weed dry weight, weed control efficiency and weed index are given in Table 10.

At 30 DAP, growing condition, different dates of planting and mulching exhibited significant influence on weed density with lower weed density observed in shaded condition (177.28 no. m^{-2}) while open condition recorded weed density of 204.03 no. m^{-2}. Among different dates of planting, the lowest weed density was noticed in plots of July planting (160.61 no. m^{-2}) which was on par with August planting (161.22 no. m^{-2}). At this stage, higher weed density was observed in 15th June planted plots (243.28 no. m^{-2}). Mulching had significant effect on weed count and black polythene sheet recorded lower weed density (16.42 no. m^{-2}) followed by paddy straw mulching (184.38 no. m^{-2}). Higher weed density was observed in plots without any mulch (371.17 no. m^{-2}).

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Table 8. Effect of treatments on total chlorophyll content at different growth stages and andrographolide content of kiriyath

Treatments	Total chlorophyll (mg g^{-1})			Andrographolide (%)
	30 DAP	60 DAP	Harvest	Harvest
Growing condition				
Open	1.06	1.57	1.61	0.96
50% Shade	1.00	1.72	2.23	1.05
CD (0.05)	NS	0.09	0.09	0.01
Planting Date				
15-May	1.11	1.75	2.22	1.00
15-Jun	0.91	1.99	2.21	0.96
15-Jul	0.77	1.36	1.52	1.01
15-Aug	1.32	1.47	1.72	1.04
CD (0.05)	0.08	0.12	0.13	0.02
Mulching				
No mulch	1.18	1.72	1.71	0.97
Paddy straw mulch	0.82	1.47	2.08	1.05
Black polythene mulch	1.08	1.73	1.96	0.99
CD (0.05)	0.07	0.11	0.11	0.02

Table 9. Effect of treatments on crop growth rate and relative growth rate kiriyath at different growth stages

Treatments	CGR (g $m^{-2}day^{-1}$)		RGR (g $g^{-1}day^{-1}$)	
	30 to 60 DAP	60 DAP to Harvest	30 to 60 DAP	60 DAP to Harvest
Growing condition				
Open	1.56	8.13	0.076	0.031
50% Shade	1.50	8.02	0.065	0.03
CD (0.05)	NS	NS	0.003	NS
Planting Date				
15-May	1.65	9.17	0.073	0.032
15-Jun	2.09	10.10	0.079	0.03
15-Jul	1.27	5.86	0.068	0.029
15-Aug	1.10	7.19	0.063	0.033
CD (0.05)	0.127	0.48	0.004	NS
Mulching				
No mulch	1.14	8.10	0.067	0.033
Paddy straw mulch	1.33	7.13	0.070	0.031
Black polythene mulch	2.11	8.99	0.074	0.029
CD (0.05)	0.11	0.42	0.004	0.001

At 60 DAP, effect of growing condition on total weed density was non significant. However, dates of planting and mulching exhibited significant influence on weed denity. July planted plots recorded lower weed density of (91.44 no. m^{-2}) which were on par with May planting (112.00 no. m^{-2}). At this stage also June planting (201.11 no. m^{-2}) resulted in higher weed density. At 60 DAP also black polythene sheet mulch continued its superiority in preventing weed establishment and recorded the lowest weed density of 10.92 no. m^{-2}. Higher weed density was noticed in plots without mulch (244.67 no. m^{-2}).

Weed dry weight

At 30 DAP, growing condition, different dates of planting and mulching showed significant influence on weed dry weight. Weed dry weight was higher under open condition (65.34 g m^{-2}).

May planting and no mulching recorded higher weed dry weight of (73.97 g m^{-2} and 100.05 g m^{-2} respectively) at 30 DAP. Lower weed dry weight was recorded under shaded condition (52.23 no. m^{-2}), August planting (50.19 g m^{-2}) and mulching with black polythene sheet (8.66 g m^{-2}).

At 60 DAP, weed dry weight was higher in open condition (47.17 g m^{-2}) than in shaded condition (36.46g m^{-2}). Plots planted on 15th July recorded the lowest weed dry weight of (30.19 g m^{-2}) and was on par with June planting (41.58 g m^{-2}). August planting recorded higher weed dry weight of 50.19 g m^{-2}, which was on par with May planting (44.89 g m^{-2}). Mulching followed the similar trend at 30 DAP with higher weed dry weight in no mulch condition (71.26 g m^{-2}) and the lowest under black polythene sheet mulching (8.66 g m^{-2}).

Table 10. Effects of treatments on weed density and weed dry weight

Treatments	Weed count (no. m^{-2})		Weed dry weight ($g\ m^{-2}$)	
	30 DAP	60 DAP	30 DAP	60 DAP
Growing condition				
Open	12.43** (204.03)	9.99 (128.44)	7.34 (65.34)	6.43 (47.17)
50% Shade	11.71 (177.28)	10.22 (139.94)	6.87 (52.23)	5.65 (36.46)
CD (0.05)	0.55	NS	0.38	0.17
Planting Date				
15-May	12.57 (197.50)	9.18 (112.00)	8.14 (73.97)	6.26 (44.89)
15-Jun	14.00 (243.28)	12.24 (201.11)	7.80 (65.96)	5.77 (41.58)
15-Jul	10.72 (160.61)	8.55 (91.44)	6.65 (55.65)	5.36 (30.19)
15-Aug	10.98 (161.22)	10.45 (132.22)	5.82 (39.57)	6.77 (50.19)
CD (0.05)	0.78	0.89	0.54	0.24
Mulching				
No mulch	19.10 (371.17)	15.21 (244.67)	9.91 (100.05)	8.36 (71.26)
Paddy straw mulch	13.50 (184.38)	11.89 (147.00)	7.86 (61.74)	6.77 (45.52)
Black polythene mulch	3.59 (16.42)	3.21 (10.92)	3.54 (14.57)	2.99 (8.66)
CD (0.05)	0.68	0:77	0.47	0.21

** $\sqrt{x+0.5}$ transformed values, original values are given in parenthesi

4.1.6. Weather observations

Various weather parameters experienced by the crop from sowing to harvest were recorded and are presented in Table 11. The weather parameters like maximum and minimum temperature, forenoon and afternoon relative humidity, wind speed, solar radiation and rainfall were recorded on daily basis and converted to weekly observations.

Air temperature

The average maximum temperature ranged from 29.6 °C to 34.7 °C in open condition and 26.6°c to 33.5°c in shaded condition. The highest maximum temperature was recorded on 1st week and lowest on 7th week in the open condition. Under shade, lowest maximum temperature was recorded on 29th week and the highest was observed on 2nd week. The lowest minimum temperature (22.0 °C) was recorded on 10th week and highest minimum temperature (25.6 °C) was recorded on 1st week under open condition.

Relative Humidity

The forenoon relative humidity ranged from 67.5% to 95.7% in open condition and in shade it ranged from 63% to 95.7%. In open condition, higher forenoon relative humidity was observed in 5th week and the lowest in 33rd week. Under 50% shaded condition, 26th week recorded highest forenoon relative humidity and 34th week observed lowest forenoon relative humidity.

The lowest afternoon relative humidity under open condition (34.8%) was recorded on 33rd week and highest (82.4%) on 6th week and 18th week. In the case of 50 per cent shaded condition, highest afternoon relative humidity was observed on 35th week (34.4%).

Wind speed

No significant difference between open and shaded condition was observed for wind speed. Wind speed ranged from 0.1 km hr^{-1} to 7.9 km hr^{-1}. The maximum wind speed was recorded on 32nd week and lower wind speed was observed during 21st, 22nd, and 23rd weeks.

Solar radiation

Solar radiation ranged from 202 Wm^{-2} to 1129 Wm^{-2} in open condition with highest number of sunshine hours recorded on 10th week and lowest on 8th week. Under 50% shaded condition highest number of sunshine hours (343 Wm^{-2}) was noticed in 1st week and minimum was observed on 5th week (129 Wm^{-2}).

Rainfall

The rainfall received during crop period ranged from 4.5 mm to 313.6 mm. There was no rainfall recorded from 26th week to 35th week. Highest rainfall (313.66 mm) was recorded on 7th week. The total rainfall received during the period was 2255.8 mm.

4.1.7. Crop weather correlations

Simple linear correlation between important morphological, yield and quality characters and mean weekly weather parameters like surface air temperature, relative humidity (forenoon and afternoon), wind speed, solar radiation and rainfall were carried out and the coefficients have been presented in Tables 12, 13, 14, 15, 16, 17 and 18.

Table 11. Weather experienced during the crop period

Weeks	Tmax(°C)		Tmin(°C)		Fore noon relative humidity (%)		After noon relative humidity (%)		Wind speed (km hr^{-1})	Solar radiation (Wm^{-2})		Rainfall (mm)
	Open	Shade	Open	Shade	Open	Shade	Open	Shade		Open	Shade	
Week 1	34.7	32.6	25.6	25.8	88.7	91.4	59.3	72.1	1.9	934.6	343.7	16.6
Week2	33.9	33.5	25.1	25.6	88.0	92.9	62.3	64.9	1.8	909.3	205.0	30.6
Week3	30.6	32.9	23.6	25.2	92.7	88.6	74.0	68.3	1.3	901.2	186.6	120.0
Week4	30.4	32.1	23.9	24.4	93.6	93.6	79.0	70.3	1.0	838.2	169.6	128.0
Week5	30.7	30.6	25.1	23.4	95.7	95.1	75.0	76.3	1.7	779.6	129.0	72.2
Week6	29.8	30.7	23.1	25.0	94.6	93.4	82.4	84.7	3.0	775.3	156.8	114.1
Week7	29.6	30.7	22.4	23.9	96.4	95.6	80.3	78.1	1.4	297.7	163.4	313.6
Week8	30.3	31.7	22.8	24.1	95.3	94.6	78.0	72.6	1.8	202.7	133.8	63.9
Week9	30.5	28.1	23.5	22.4	95.0	85.8	71.6	55.6	2.3	966.3	323.1	119.0
Week10	30.8	28.7	22.0	22.5	89.7	83.0	78.9	49.0	1.3	1129.9	236.0	153.7
Week11	32.0	29.4	23.4	23.8	94.3	83.0	65.3	48.1	1.7	1088.7	239.7	16.8
Week12	29.8	28.9	23.7	23.8	95.6	83.0	77.9	48.6	1.4	817.3	199.3	145.7
Week13	31.0	29.0	23.6	23.3	94.6	85.4	71.9	48.0	1.1	932.6	199.5	22.2
Week14	30.2	28.0	23.1	23.1	96.7	95.1	80.9	48.0	0.8	862.9	186.6	125.5
Week15	30.1	27.8	23.1	23.7	96.0	95.1	80.7	48.0	0.9	624.6	154.3	121.3
Week16	30.0	29.3	24.1	23.5	94.0	95.1	74.9	47.1	0.9	1050.7	232.3	111.1
Week17	31.7	29.2	23.4	23.3	95.4	94.9	72.9	47.3	0.6	1039.7	196.1	35.3
Week18	31.7	27.8	22.5	22.0	96.7	95.1	82.4	46.3	0.8	956.1	210.2	263.2
Week19	31.8	29.0	22.8	23.3	92.9	85.7	67.0	46.0	0.8	926.3	223.2	28.6
Week20	30.7	29.0	22.5	23.4	95.4	79.7	70.9	47.0	0.2	830.9	200.9	98.5

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Weeks	Tmax(°C)		Tmin(°C)		Fore noon relative humidity (%)		After noon relative humidity (%)		Wind speed (km hr^{-1})	Solar radiation (W m^{-2})		Rainfall (mm)
	Open	Shade	Open	Shade	Open	Shade	Open	Shade		Open	Shade	
Week21	31.5	29.6	22.8	24.3	93.0	73.6	68.7	51.3	0.1	971.7	208.7	4.5
Week22	31.3	28.6	22.5	23.4	94.4	77.7	77.7	49.1	0.1	834.4	188.0	41.7
Week23	31.2	28.3	22.2	21.4	94.6	74.3	73.4	48.0	0.1	913.4	226.4	27.0
Week24	32.4	28.6	21.6	22.6	90.9	84.7	61.3	47.7	0.6	1023.6	250.6	49.3
Week25	32.9	27.8	22.3	22.6	79.1	91.3	64.1	49.6	2.0	966.0	225.3	33.4
Week26	32.7	27.0	21.5	20.0	88.6	95.7	54.4	46.9	1.5	935.0	241.5	0.0
Week27	33.0	27.5	21.3	22.2	92.7	91.4	59.1	46.1	0.6	910.9	242.6	0.0
Week28	33.3	27.0	21.7	22.4	88.1	90.9	54.6	55.1	2.0	804.7	194.3	0.0
Week29	31.8	26.6	22.4	23.6	82.6	86.6	60.4	49.4	5.6	942.4	218.8	0.0
Week30	33.3	26.7	21.0	23.8	91.3	95.4	59.1	45.1	0.8	764.9	185.4	0.0
Week21	32.2	28.3	21.4	25.0	80.4	90.0	51.9	48.6	4.9	942.0	253.8	0.0
Week32	32.5	29.5	21.2	23.8	67.9	89.4	41.1	43.4	7.9	949.1	260.1	0.0
Week33	32.8	28.5	20.1	19.1	67.5	74.6	34.8	39.7	6.8	918.0	254.9	0.0
Week34	34.0	29.8	18.2	20.6	89	63.0	40	43.7	3.3	830.0	227.6	0.0
Week35	33.8	31.4	18.2	18.5	91	63.4	48	34.4	1.5	931.4	246.3	0.0

Plant height

Generally plant height was negatively correlated with maximum temperature (correlation coefficient between -0.534 to -0.863) during initial crop stages. Minimum temperature had a positive correlation with plant height during 7^{th} week and near flowering stage. Forenoon relative humidity had significant negative correlation during the initial stages till flowering stage. Afternoon relative humidity also had negative correlation with the plant height. Solar radiation also had a negative effect on plant height. Wind speed and rainfall did not exhibit any effect on plant height.

Number of branches per plant

Number of branches were not associated with maximum temperature during the initial stages but later on it was negatively correlated. In general, minimum temperature had positive correlation throughout the crop period. Forenoon relative humidity was negatively correlated with number of branches during the initial stages. Number of branches were negatively correlated to afternoon relative humidity during the vegetative and reproductive stages. Solar radiation was negatively correlated with number of branches. Here also neither wind speed nor rainfall affected the number of branches.

Days to first flowering

Days to first flowering was influenced by weather factors. As observed in case of plant height and number of branches, days to first flower was negatively influenced by maximum temperature. As temperature increases plants takes minimum days to flower and this character was positively correlated with the minimum temperature. Forenoon relative humidity influenced flowering at 60 DAP and exhibited no influence during initial and later stages, whereas, afternoon relative humidity affected the crop

Table 12. Correlation between biometric characters and maximum temperature

Weeks	1	2	3	4	5	6	7	8	9	10
Plant height	-0.534**	-0.355	-0.126	-0.340	-0.593**	-0.714**	-0.708**	-0.311	-0.708**	-0.827**
Number of branches	-0.047	0.063	-0.014	-0.085	-0.568**	-0.514*	-0.452*	-0.091	-0.891**	-0.835**
Days to first flowering	-0.159	0.010	0.212	0.265	-0.624**	-0.499*	-0.318	-0.196	-0.887**	-0.881**
Biomass yield	0.617**	0.636**	0.233	0.519**	0.137	0.086	0.043	0.210	-0.573**	-0.369
Andrographolide content	-0.432	-0.254	0.074	-0.006	-0.503*	-0.365	-0.575**	-0.060	-0.697**	-0.588**

Weeks	11	12	13	14	15	16	17	18	19	20
Plant height	-0.683**	-0.591**	-0.629**	-0.697**	-0.722**	-0.633**	-0.801**	-0.897**	-0.870**	-0.863**
Number of branches	-0.688**	-0.666**	-0.707**	-0.798**	-0.775**	-0.770**	-0.772**	-0.863**	-0.840**	-0.873**
Days to first flowering	-0.868**	-0.631**	-0.699**	-0.832**	-0.736**	-0.629**	-0.708**	-0.879**	-0.894**	-0.799**
Biomass yield	-0.248	-0.322	-0.304	-0.461*	-0.391	-0.390	-0.248	-0.368	-0.386	-0.452*
Andrographolide content	-0.468*	-0.392	-0.707**	-0.646**	-0.659**	-0.604**	-0.650**	-0.655**	-0.534**	-0.630**

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 13. Correlation between plant characters and minimum temperature

Weeks	1	2	3	4	5	6	7	8	9	10
Plant height	-0.425*	-0.032	0.355	0.364	-0.289	0.351	0.698**	0.353	-0.083	-0.267
Number of branches	0.073	0.589**	0.507*	0.496*	0.147	0.466*	0.560**	0.179	0.202	-0.197
Days to first flowering	-0.014	0.527**	0.533**	0.578**	-0.369	0.423*	0.860**	0.476*	-0.248	0.185
Biomass yield	0.578**	0.945**	0.508*	0.573**	0.269	0.400	0.094	-0.232	-0.258	0.035
Andrographolide content	-0.427*	0.185	0.644**	0.444*	-0.581**	0.566**	0.379	0.375	-0.434*	-0.532**

Weeks	11	12	13	14	15	16	17	18	19	20
Plant height	0.375	0.119	0.214	0.487*	-0.232	0.099	0.262	-0.236	0.289	0.214
Number of branches	0.553**	0.415*	0.143	0.412*	0.315	0.666**	0.568**	0.154	0.565**	0.309
Days to first flowering	0.656**	0.398	0.208	0.260	0.427*	0.408*	0.626*	0.153	0.295	0.435*
Biomass yield	0.566**	0.574**	0.246	0.274	0.702**	0.878**	0.536**	0.237	0.433*	0.485*
Andrographolide content	-0.026	-0.407*	-0.433*	-0.50	-0.092	0.261	0.209	0.201	0.360	-0.210

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 14. Correlation between plant characters and forenoon relative humidity

Weeks	1	2	3	4	5	6	7	8	9	10
Plant height	-0.595**	-0.517**	-0.782**	-0.817**	-0.699**	-0.048	-0.211	-0.172	-0.297	-0.217
Number of branches	-0.501*	-0.184	-0.505*	-0.459*	-0.441*	-0.320	-0.332	-0.275	-0.529**	-0.483*
Days to first flowering	-0.236	-0.039	-0.366	-0.316	-0.615**	-0.475*	-0.431*	-0.315	-0.589**	-0.291
Biomass yield	-0.349	-0.022	-0.142	-0.007	-0.063	-0.239	-0.080	-0.019	-0.293	-0.334
Andrographolide content	-0.111	0.024	-0.351	-0.235	-0.233	-0.233	-0.493*	-0.577**	-0.684**	-0.623**

Weeks	11	12	13	14	15	16	17	18	19	20
Plant height	-0.685**	-0.487*	-0.757**	-0.821**	-0.742**	-0.309	0.044	0.217	0.112	0.046
Number of branches	-0.567**	-0.295	-0.382	-0.334	-0.344	-0.128	-0.243	-0.209	-0.032	-0.010
Days to first flowering	-0.457*	-0.192	-0.311	-0.228	-0.352	-0.252	-0.181	-0.073	-0.170	-0.055
Biomass yield	-0.114	0.000	0.037	0.259	0.168	0.131	0.248	0.144	0.159	0.095
Andrographolide content	-0.782**	-0.442*	-0.332	-0.404	-0.319	-0.467*	0.027	-0.204	-0.318	-0.558**

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 15. Correlation between plant characters and afternoon relative humidity

Weeks	1	2	3	4	5	6	7	8	9	10
Plant height	-0.483*	-0.643**	-0.714**	-0.796**	-0.716**	-0.599**	-0.619**	-0.745**	-0.845**	-0.836**
Number of branches	-0.399	-0.548**	-0.339	-0.528**	-0.477*	-0.398	-0.460*	-0.531**	-0.781**	-0.823**
Days to first flowering	-0.080	-0.212	-0.188	-0.390	-0.487*	-0.415*	-0.509*	-0.596**	-0.858**	-0.879**
Biomass yield	-0.051	-0.149	0.270	0.114	0.097	0.103	0.057	0.004	-0.281	-0.353
Andrographolide content	-0.385	-0.536**	-0.645**	-0.698**	-0.485**	-0.563**	-0.428**	-0.655**	-0.669**	-0.796**

Weeks	11	12	13	14	15	16	17	18	19	20
Plant height	-0.769**	-0.817**	-0.659**	-0.721**	-0.688**	-0.779**	-0.757**	-0.634**	-0.532**	-0.173
Number of branches	-0.728**	-0.712**	-0.650**	-0.691**	-0.605**	-0.598**	-0.639**	-0.340	-0.413*	-0.092
Days to first flowering	-0.744**	-0.854**	-0.749**	-0.779**	-0.791**	-0.808**	-0.762**	-0.567**	-0.462*	-0.240
Biomass yield	-0.334	-0.206	-0.246	-0.244	-0.170	-0.077	-0.106	0.157	-0.048	0.184
Andrographolide content	-0.891**	-0.824**	-0.878**	-0.871**	-0.669**	-0.832**	-0.879**	-0.825**	-0.877**	-0.667**

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 16. Correlation between plant characters and solar radiation

Weeks	1	2	3	4	5	6	7	8	9	10
Plant height	-0.741**	-0.725**	-0.650**	-0.638**	-0.834**	-0.818**	-0.672**	-0.585**	-0.824**	-0.826**
Number of branches	-0.773**	-0.814**	-0.739**	-0.654**	-0.861**	-0.815**	-0.738**	-0.880**	-0.805**	-0.752**
Days to first flowering	-0.893**	-0.855**	-0.841**	-0.809**	-0.874**	-0.853**	-0.651**	-0.726**	-0.869**	-0.904**
Biomass yield	-0.324	-0.407*	-0.354	-0.239-	0.431*	-0.404	-0.504*	-0.756**	-0.317	-0.228
Andrographolide content	-0.692**	-0.724**	-0.335	-0.278	-0.765**	-0.813**	-0.708**	-0.486*	-0.768**	-0.728**

Weeks	11	12	13	14	15	16	17	18	19	20
Plant height	-0.784**	-0.832**	-0.831**	-0.847**	-0.774**	-0.808**	-0.807**	-0.819**	-0.834**	-0.847**
Number of branches	-0.728**	-0.803**	-0.823**	-0.806**	-0.881**	-0.797**	-0.773**	-0.809**	-0.813**	-0.796**
Days to first flowering	-0.909**	-0.870**	-0.904**	-0.901**	-0.865**	-0.916**	-0.876**	-0.932**	-0.918**	-0.873**
Biomass yield	-0.221	-0.359	-0.372	-0.339	-0.530**	-0.310	-0.286	-0.339	-0.343	-0.337
Andrographolide content	-0.567**	-0.790**	-0.785**	-0.775**	-0.770**	-0.706**	-0.819**	-0.707**	-0.745**	-0.797**

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 17. Correlation between plant characters and wind speed

Weeks	1	2	3	4	5	6	7	8	9	10
Plant height	0.275	-0.168	0.306	0.073	-0.181	-0.155	-0.080	-0.055	-0.108	0.040
Number of branches	0.016	0.093	-0.083	-0.071	0.156	0.361	0.169	0.258	0.333	0.245
Days to first flowering	0.140	0.326	0.114	0.243	0.343	0.198	0.339	0.305	0.252	0.246
Biomass yield	-0.027	0.326	-0.239	-0.100	0.458*	0.816**	0.448*	0.606**	0.758**	0.533**
Andrographolide content	-0.293	-0.518**	-0.308	-0.502*	-0.510*	-0.126	-0.511*	-0.400	--0.249	-0.315

Weeks	11	12	13	14	15	16	17	18	19	20
Plant height	-0.090	-0.322	-0.313	-0.403	-0.294	-0.122	0.403	-0.029	-0.120	-0.031
Number of branches	0.342	0.149	0.166	0.270	0.050	-0.072	-0.201	-0.126	-0.083	-0.174
Days to first flowering	0.201	-0.081	-0.081	0.213	-0.128	-0.262	-0.221	-0.307	-0.263	-0.298
Biomass yield	0.756**	0.383	0.412*	0.724**	0.166	-0.169	-0.592**	-0.318	-0.191	-0.409*
Andrographolide content	-0.152	0.290	0.298	-0.167	0.313	0.460*	0.223	0.495*	0.454*	0.450*

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 18. Correlation between plant characters and rainfall

Weeks	1	2	3	4	5	6	7	8	9	10
Plant height	0.183	0.233	-0.309	0.299	-0.263	0.083	0.006	0.105	-0.084	0.348
Number of branches	-0.348	-0.370	0.078	0.062	-0.039	0.043	0.286	-0.058	0.331	-0.062
Days to first flowering	-0.266	-0.170	0.258	0.049	-0.146	0.280	0.019	0.241	0.069	0.056
Biomass yield	-0.818**	-0.852**	0.326	0.033	-0.026	0.129	0.566**	-0.087	-0.697**	-0.226
Andrographolide content	0.254	0.056	-0.379	-0.102	0.287	-0.504*	0.134	-0.496*	0.082	-0.197

Weeks	11	12	13	14	15	16	17	18	19	20
Plant height	-0.194	0.014	-0.210	-0.187	-0.063	-0.088	0.253	-0.140	-0.246	-0.205
Number of branches	-0.090	0.238	0.178	0.119	0.334	0.247	0.124	0.360	0.289	0.351
Days to first flowering	0.176	0.275	0.343	0.333	0.185	0.325	.039	0.178	0.328	0.268
Biomass yield	-0.065	0.536**	0.512*	0.384	0.727**	0.600**	0.167	0.802**	0.738**	0.831**
Andrographolide content	-0.347	-0.368	-0.493*	-0.512*	-0.132	-0.438*	-0.040	-0.092	-0.393	-0.253

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed) negatively during all the stages except initial weeks. Solar radiation had strong negative correlation with days to flowering. Wind speed and rainfall did not exhibit any effect on days to first flowering.

Biomass yield

During the initial seedling stage biomass was positively correlated with maximum temperature. Later at flowering and harvesting stage it was negatively correlated. Minimum temperature also was positively correlated with biomass yield and exhibited strong positive correlation during flowering stage (correlation coefficient - 0.878). Rainfall had negative correlation with biomass yield initially but later on it influenced biomass positively.

Andrographolide content

Maximum temperature negatively influenced andrographolide content during the vegetative stages, flowering and final stages. At flowering stage, minimum temperature had no effect on andrographolide content. Afternoon relative humidity has negative correlation with the andrographolide content during flowering stage and harvesting stage (correlation coefficient – -0.832). Solar radiation also negatively influenced the andrographolide content in the plants.

4.2. Two factor interactions

4.2.1. Interaction between growing condition and planting dates

4.2.1. a Biometric observations

Plant height at 30, 60 DAP and at harvest

Interaction between growing condition and planting dates on plant height, number of branches and days to first flowering are depicted in Table 19. At 30 DAP, there was no significant interaction for plant height. However, interaction was significant at 60 DAP and at harvest. At 60 DAP, planting in July under 50 per cent shaded condition or in August under shade was found to be better with respect to plant height (35.77 cm and 35.09 cm respectively). Planting in May under open condition recorded the lowest plant height (7.82 cm). At harvest, planting in July under 50 per cent shade produced taller plants (99.56 cm) followed by planting under 50 per cent shade in May, August and June (77.93 cm, 75.63 cm and 72.32 cm respectively).

Number of branches per plant at 30, 60 DAP and at harvest

At 30 DAP, no branching was observed and at 60 DAP, the data was non significant. At harvest, highest number of branches was noticed in the treatment combination May planting under 50 per cent shade (23.60). It was on par with planting under 50 per cent shade in July (23.04), June (22.48), August (22.31) and planting in May under open condition (21.28).

Days to first flowering

Significant variations among treatment combinations were observed with respect to days to first flowering (Table 19). Number of days taken for first flowering ranged from 108 to 126. Crop planted in July under 50 per cent shaded condition took maximum number of days for flowering (126 days) followed by July planting under open (111 days).

Table 19. Interaction effect of growing condition and planting dates on plant height, number of branches and days to first

flowering of kiriyath at different growth stages

Treatments	Plant height (cm)						Number of branches				Days to first flowering	
	30 DAP		60 DAP		Harvest		60 DAP		Harvest			
	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade
May	4.64	7.04	7.82	12.71	55.34	77.93	5.38	5.51	21.28	23.60	109.17	107.50
June	4.55	7.10	15.33	23.77	57.22	72.32	7.16	7.06	19.82	22.48	109.33	108.00
July	4.66	6.88	22.16	35.77	59.96	99.56	7.06	6.62	17.87	23.04	111.00	125.50
August	4.01	7.17	18.91	35.09	56.34	75.63	6.71	6.87	19.50	22.31	107.67	122.83
CD (0.05)	NS		1.14		3.59		NS		1.34		2.39	

Fresh biomass yield at 30, 60 DAP and at harvest

Data pertaining to interaction effect of growing condition and planting dates on biomass yield and total yield of kiriyath are presented in Table 20. As compared to planting in open, all planting dates under 50 per cent shade recorded significantly higher biomass at 30 DAP. Lower biomass was observed in open planting in May (0.98 g plant $^{-1}$), which was on par with open planting in august (1.03 g plant $^{-1}$) and open planting in June (1.19 g plant $^{-1}$).

At 60 DAP planting in July under 50 per cent shade recorded higher biomass (14.83 g plant $^{-1}$) which was on par with planting in June either in shade or open (14.33 g plant $^{-1}$ and 14.32 g plant $^{-1}$ respectively), planting in August under shade (13.77 g plant $^{-1}$) and planting in May under open (13.32 g plant $^{-1}$). At harvest planting in May either in open or shade gave higher biomass of 144.82 and 143.04 g plant^{-1} respectively. Planting in July under open condition recorded the lowest biomass at this stage (57.51 g plant $^{-1}$).

Total yield

Higher total yield was observed in May planting under open condition (12964 kg ha^{-1}), which was on par with May planting under shade (12781 kg ha^{-1}). Planting in June under 50 per cent shade was the next best treatment with total yield of 11332 kg ha^{-1}. Planting in July under open condition recorded lowest yield of 3943 kg ha^{-1}.

4.2.1. b Soil analysis

Soil pH

Interaction effect between growing condition and planting date on soil pH was non significant (Table 21).

Table 20. Interaction effect of growing condition and planting dates on biomass yield and total yield of kiriyath

Treatments	Biomass Yield (g $plant^{-1}$)						Total Yield (kg ha^{-1})	
	30 DAP		60 DAP		Harvest		Harvest	
	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade
May	0.98	2.14	13.32	11.59	144.82	143.04	12,964	12,781
June	1.19	2.09	14.32	14.33	92.02	129.02	7,509	11,332
July	1.22	1.96	6.51	14.83	57.51	94.62	3,943	7,778
August	1.03	2.03	7.43	13.77	94.21	98.59	7,735	8,188
CD (0.05)	0.21		1.62		9.04		934	

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Organic carbon

Interaction effect of growing condition and planting date could not bring any significant effect on organic carbon content of soil (Table 21).

Available nitrogen

Interaction between growing condition and planting date on available N content was found non significant (Table 21).

Available phosphorus

There was no significant influence of growing condition and different dates of planting on available soil phosphorus content (Table 21).

Available potassium

The interaction between growing condition and planting dates had no significant effect on available soil K.

4.2.1. c Micrometeorological observations

Soil temperature

Table 22. depicts the interaction between growing condition and planting date on soil temperature. Temperature ranged from 25.2 °C to 29 °C. The highest soil temperature was recorded in 1st week of May planting in open condition and lower was recorded under shaded condition in all the planting dates with 25.2 °C in 16th week of May planting, 13th week of June planting, 9th, 14th and 16th weeks of July planting and finally 4th, 9th and 11th weeks of August planted plots.

Table 21. Interaction effect of growing condition and planting dates on soil pH, organic carbon and available N, P and K after the experiment

Treatments	pH		Organic carbon (%)		Available N (kg ha $^{-1}$)		Available P (kg ha $^{-1}$)		Available K (kg ha $^{-1}$)	
	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade
May	5.55	5.18	2.02	2.09	247.56	247.14	10.17	10.37	166.76	160.27
June	5.50	5.38	1.98	2.23	242.33	247.40	9.92	10.53	165.20	164.44
July	5.31	5.24	1.92	2.07	247.63	247.04	10.59	10.12	160.14	167.30
August	5.20	5.25	1.88	1.96	240.72	249.00	9.81	10.08	161.51	161.65
CD (0.05)	NS		NS		NS		NS		NS	

Soil moisture

The data on interaction effect of growing condition and planting date on soil moisture are presented in Table 23. Interaction had significant influence on soil moisture at all the stages. Moisture content ranged from 100 % to 13.45 %.

4.2.1.d Physiological, chemical and biochemical observations

Total chlorophyll content 30 DAP, 60 DAP and at harvest

Interaction between growing condition and planting dates on total chlorophyll content and andrographolide content are depicted in Table 24. Interaction effect showed significant influence on total chlorophyll content except at harvest. At 30 DAP, higher chlorophyll content was recorded in August planting in shaded condition (1.48 mg g^{-1}) and crop planted in July under shade (0.66 mg g^{-1}) had minimum total chlorophyll content. At 60 DAP, maximum chlorophyll content (2.01 mg g^{-1}) was recorded with June planting in 50 per cent shade. Crop planted in August in open condition recorded minimum chlorophyll content (1.25 mg g^{-1}). At harvest, data was non significant.

Andrographolide content (%)

Andrographolide content at harvest was significantly influenced by the interaction between growing condition and planting date. Higher andrographolide content was obtained from August planting in shaded condition (1.08 %) which was on par with May planting in shaded condition. Andrographolide content from June planting in open condition was minimum (0.90 %).

Crop growth rate

Interaction effect of growing condition and planting date on crop growth rate and relative growth rate are given in Table 25. June planting in open condition recorded higher crop growth rate (2.50 g m^{-2} day^{-1}). August planting in open condition recorded lower CGR (0.91 g m^{-2} day^{-1}) and was on par with July planting in open condition (0.95 g m^{-2} day^{-1}).

At 60 DAP to harvest significantly higher crop growth rate was recorded in June planting under shaded condition (10.26 g m^{-2} day^{-1}) and was on par with June planting in open condition (9.88 g m^{-2} day^{-1}). Lower CGR was recorded in July under shaded condition (5.39 g m^{-2} day^{-1}).

Relative growth rate

Significantly higher RGR during 30 to 60 DAP was recorded in June planting in open condition (0.089 g g^{-1} day^{-1}) and was on par with May planting in open condition (0.085 g g^{-1} day^{-1}). Lower RGR was recorded in May planting under shaded condition (0.060 g g^{-1} day^{-1}). At 60 DAP to harvest, August planting in open condition recorded higher RGR (0.035 g g^{-1} day^{-1}) which was on par with May planting in shaded condition (0.034 g g^{-1} day^{-1}). Minimum RGR was observed in July planting under shaded condition (0.026 g g^{-1} day^{-1}).

4.2.1. e Observations on weeds

Weed density

Table 26. depicts interaction effect of growing condition and planting date on weed density, weed dry weight. At 30 DAP, June planting in open condition (290.45 no. m^{-2}) recorded maximum weed density and minimum was seen in August planting in open condition (159.67 no. m^{-2}). At 60 DAP, higher weed density was noticed in the treatment combination June planting and open condition (196.11 no. m^{-2}). Crop planted in July in open field had lower weed density (70.89 no. m^{-2}) and was on par with May planting in open (76.22 no. m^{-2}) and July planting in shade (112 no. m^{-2}).

Table 22. Interaction effect of growing condition and planting dates on soil temperature

Treatments	Soil temperature (°C)																			
	Week1		Week 2		Week 3		Week 4		Week 5		Week 6		Week 7		Week 8		Week 9		Week 10	
	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S
May	29.0	26.9	27.4	25.6	25.5	25.5	28.4	26.5	27.0	25.7	27.8	26.2	27.5	26.2	27.1	25.6	27.6	25.9	29.0	26.8
June	28.4	26.5	27.1	25.7	27.8	26.2	27.4	26.2	27.2	25.7	27.6	26.0	29.0	26.7	28.3	26.2	27.8	25.6	27.8	25.8
July	27.2	25.7	27.6	26.0	29.0	26.8	28.3	26.2	27.8	25.6	27.8	25.8	28.5	26.3	28.3	26.2	26.5	25.2	27.4	25.9
August	27.9	25.8	27.8	26.3	28.4	26.3	28.3	25.2	26.5	25.9	27.4	25.3	27.0	25.7	27.7	25.5	27.5	25.2	27.1	25.6
CD (0.05)	0.09		0.07		0.18		0.09		0.08		0.08		0.09		0.14		0.09		0.06	

Treatments	Soil temperature (°C)																			
	Week11		Week 12		Week 13		Week 14		Week 15		Week 16		Week 17		Week 18		Week 19		Week 20	
	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S
May	28.4	26.3	27.9	25.7	27.8	25.8	28.5	26.4	28.3	26.3	26.5	25.2	27.5	25.9	26.5	25.3	27.5	25.9	27.5	26.0
June	28.5	26.4	28.3	26.3	26.5	25.2	27.5	25.9	27.1	25.4	27.7	25.7	27.6	25.6	27.1	26.0	27.1	26.1	27.5	25.8
July	26.7	25.4	27.8	25.7	27.6	25.6	27.1	25.2	28.1	25.6	27.5	25.2	27.5	25.5	26.9	25.9	26.7	25.8	26.6	25.6
August	28.1	25.2	27.5	25.5	27.5	26.2	27.1	26.0	27.4	26.3	26.6	25.7	26.4	25.5	27.2	26.2	27.9	26.9	27.0	25.9
CD (0.05)	0.35		0.02		0.03		0.03		0.04		0.13		0.03		0.02		0.04		0.04	

Table 23. Interaction effect of growing condition and planting dates on soil moisture at 15 cm depth

Treatments	Soil moisture (%)									
	14 DAP		28 DAP		42 DAP		56 DAP		60 DAP	
	O	S	O	S	O	S	O	S	O	S
May	13.52	15.39	14.52	14.42	100.03	100.03	13.87	13.59	16.07	17.87
June	14.77	16.81	14.72	17.69	15.89	17.71	13.45	13.52	14.00	14.51
July	16.05	17.94	14.97	18.22	14.42	13.85	13.88	15.83	100.03	100.03
August	14.79	17.20	14.51	13.86	100.02	100.02	13.30	15.54	13.43	15.41
CD (0.05)	0.02		0.01		0.04		0.02		0.02	

Treatments	Soil moisture (%)									
	74 DAP		88 DAP		102 DAP		116 DAP		130 DAP	
	O	S	O	S	O	S	O	S	O	S
May	13.30	14.03	12.88	14.11	13.07	14.76	13.56	15.06	13.86	13.78
June	14.34	15.35	15.48	16.48	13.22	14.67	13.01	14.14	13.90	13.95
July	15.08	17.44	13.83	13.80	13.15	13.95	12.95	13.29	12.29	14.18
August	13.99	14.19	12.36	14.06	13.11	14.67	11.14	13.24	10.85	13.12
CD (0.05)	0.02		0.03		0.02		0.03		0.17	

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Table 24. Interaction effect of growing condition and planting dates on total chlorophyll content at different growth stages (mg g^{-1}) and andrographolide (%)

Treatments	Total chlorophyll (mg g^{-1})						Andrographolide (%)	
	30 DAP		60 DAP		Harvest		Harvest	
	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade
May	1.22	1.00	1.72	1.78	1.89	2.56	0.95	1.05
June	0.98	0.85	1.97	2.01	1.89	2.53	0.90	1.02
July	0.88	0.66	1.32	1.39	1.31	1.74	0.98	1.03
August	1.16	1.48	1.25	1.70	1.36	2.09	1.01	1.08
CD (0.05)	0.11		0.17		NS		0.03	

Table 25. Interaction effect of growing condition and planting dates on crop growth rate, relative growth rate and andrographolide content at different growth stages

Treatments	CGR (g $m^{-2}day^{-1}$)				RGR (g $g^{-1}day^{-1}$)			
	30- 60 DAP		60 DAP- harvest		30- 60 DAP		60 DAP- harvest	
	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade
May	1.87	1.44	9.02	9.31	0.085	0.060	0.030	0.034
June	2.50	1.67	9.88	10.26	0.089	0.069	0.028	0.031
July	0.95	1.59	6.33	5.39	0.066	0.070	0.032	0.026
August	0.91	1.29	7.26	7.12	0.065	0.061	0.035	0.031
CD (0.05)	0.179		0.68		0.006		0.001	

Weed dry weight

At 30 DAP, weed dry weight was found to be non significant. However it was significant at 60 DAP. Higher weed weight was noticed in August planting under shaded condition (56.43 g m^{-2}) and lower weed dry weight was observed in June planting in shaded condition (27.75 g m^{-2}).

4.2.2. Interaction between growing condition and mulching

4.2.2. a Biometric observations

Plant height at 30, 60 DAP and at harvest

Interaction effect between growing condition and mulching on plant height, number of branches and days to first flowering are depicted in Table 27. Crop planted under shade in black polythene sheet recorded greatest plant height (8.15 cm) at 30 DAP, whereas the crop planted under open, no mulch condition recorded lower plant height (3.97 cm) and was on par with plants in open condition in paddy straw mulch. At 60 DAP, there was no significant interaction between growing condition and mulching for plant height. At harvest, mulching with black polythene sheet under 50 per cent shade resulted in taller plants (83.53 cm) and was on par with planting in paddy straw mulch under 50 per cent shaded condition. Paddy straw mulch under open condition recorded lowest plant height (54.55 cm).

Number of branches per plant at 30 DAP, 60 DAP and at harvest

At 30 DAP, no branching was observed and at 60 DAP and at harvest, the data was non significant.

Days to first flowering

With respect to days to first flowering no significant variations were observed among treatment combinations.

Fresh biomass yield at 30, 60 DAP and at harvest

Data on interaction effect of growing condition and mulching on biomass yield and total yield of kiriyath are presented in Table 28.At 30 DAP, crop planted in shaded condition and mulched with black polythene sheet produced the highest biomass yield (2.60 g plant^{-1}) and the lower biomass yield was observed in open under no mulch condition (0.98 g plant^{-1}) and was on par with paddy straw mulching in open condition (0.99 g plant^{-1}). At 60 DAP, the highest biomass yield (20.12 g plant^{-1}) was recorded in crops planted in shaded condition and mulched with black polythene sheet and lower biomass yield was recorded from crops planted in 50 per cent shade under no mulch condition (8.74 g plant^{-1}) which was on par with crops planted in no mulch and paddy straw (8.93 g plant^{-1} and 8.97 g plant^{-1} respectively) under open condition.

At harvest also the same trend that at 30 DAP and 60 DAP was seen with higher biomass yield (140 g plant^{-1}) from the crop mulched with a black polythene sheet under 50 per cent shaded condition which was on par with crop planted in black polythene sheet under open condition (135.50 g plant^{-1}). The lowest biomass yield (73.16 g plant^{-1}) was observed in crop planted without any mulch under open condition.

Total yield

The combined effect of growing condition and mulching on total yield was found significant with higher yield of 12,496 kg ha^{-1} in the treatment combination black polythene sheet mulching under 50 per cent shaded condition, and was on par with black polythene sheet mulching under open condition (12,001 kg ha^{-1}). Lower yield

Table 26. Interaction effect of growing condition and planting dates on weed density and weed dry weight at different growth stages

Treatments	Weed density (no.m^{-2})				Weed dry weight (gm^{-2})			
	30 DAP		60 DAP		30 DAP		60 DAP	
	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade
May	13.07** (217.33)	12.06 (161.56)	7.98 (76.22)	10.38 (147.78)	8.46 (55.26)	7.83 (34.53)	6.88 (55.26)	5.63 (34.53)
June	15.59 (290.45)	12.42 (196.11)	13.51 (236.67)	10.96 (165.56)	8.22 (55.40)	7.37 (27.75)	6.84 (55.40)	4.70 (27.75)
July	10.32 (159.67)	11.11 (177.67)	7.97 (70.89)	9.13 (112.00)	6.92 (33.28)	6.38 (27.11)	5.62 (33.28)	5.10 (27.11)
August	10.73 (148.67)	11.24 (173.78)	10.50 (130.00)	10.40 (134.44)	5.75 (44.74)	5.89 (56.43)	6.38 (44.74)	7.17 (56.43)
CD (0.05)	1.11		1.25		NS		0.34	

** $\sqrt{x+0.5}$ transformed values, original values are given in parenthesis

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Table 27. Interaction effect of growing condition and mulching on plant height, number of branches and days to first flowering of kiriyath at different growth stages

Treatments	Plant height (cm)						No. of branches				Days to first flowering	
	30 DAP		60 DAP		Harvest		60 DAP		Harvest			
	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade
No mulch	3.97	5.94	14.68	24.85	58.55	79.38	5.83	5.90	18.89	21.63	109.00	116.63
Paddy straw	4.49	6.90	14.15	25.93	54.55	81.17	6.46	6.17	18.84	22.53	109.13	114.75
Black polythene	4.92	8.15	19.33	29.72	58.65	83.53	7.43	7.48	21.13	24.43	109.75	116.5
CD (0.05)	0.65		NS		3.11		NS		NS		NS	

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(5,559 kg ha^{-1}) was recorded in open condition without any mulch and was on par with paddy straw mulch under open condition (6,553 kg ha^{-1}).

4.2.2. b Soil analysis

Soil pH

Data on interaction effect of growing condition and mulching on soil pH was found non significant (Table 29).

Organic carbon

A non significant interaction between growing condition and mulching could be observed only with respect to organic carbon (Table 29).

Available nitrogen

The interaction effect of growing condition and mulching did not have any significant influence on the available nitrogen content (Table 29).

Available phosphorus

Interaction effect of growing condition and mulching did not recorded significant difference in available soil phosphorus content (Table 29)

Available potassium

Significantly higher available soil K content was obtained in the treatment combination paddy straw mulch under shaded condition (188.43 kg ha^{-1}) whereas, minimum K content (137.51 kg ha^{-1}) was obtained from no mulched plots in open condition (Table 29).

Table 28. Interaction effect of growing condition and mulching on biomass yield and total yield of kiriyath

Treatments	Biomass Yield (g plant^{-1})						Total Yield (kg ha^{-1})	
	30 DAP		60 DAP		Harvest		Harvest	
	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade
No mulch	0.98	1.74	8.93	8.74	73.16	94.38	5,559	7,752
Paddy straw	0.99	1.83	8.97	12.04	82.77	114.30	6,553	9,811
Black polythene	1.36	2.60	13.28	20.12	135.50	140.28	12,001	12,496
CD (0.05)	0.18		1.40		7.83		809	

Table 29. Interaction effect of growing condition and mulching on pH, organic carbon and available N, P and K

Treatments	pH		Organic carbon (%)		Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade
No mulch	5.49	5.30	1.89	2.23	244.92	247.39	10.28	10.17	147.51	154.53
Paddy straw	5.37	5.28	1.77	2.02	246.48	244.85	10.00	10.40	187.74	188.43
Black polythene	5.31	5.21	2.17	2.02	242.28	250.69	10.09	10.27	149.96	147.29
CD (0.05)	NS		NS		NS		NS		NS	

4.2.2. c Micrometeorological observations

Soil temperature

The interaction between growing condition and mulching significantly influenced soil temperature in most of the stages except the weeks 4, 5, 11 and 16 (Table 30). Data clearly showed the increased soil temperature under black polythene sheet mulch. Here the soil temperature ranged between 24.7 ºC to 29.5 ºC with higher temperature recorded from 1st, 4th and 7th week under black polythene sheet mulch in open condition. Lower soil temperature was noticed in the 9th week under both no mulch and paddy straw mulch in open condition.

Soil moisture

From the data given in Table 31, it is clear that black polythene mulch exhibited higher soil moisture content (58.93 %) at 42 DAP under shaded condition and lower soil moisture content (11.79 %) noticed at 116 DAP in no mulch open condition.

4.2.2. d Physiological, chemical and biochemical

Total chlorophyll content 30 DAP, 60 DAP and at harvest

Interaction between growing condition and mulching ssignificantly influenced total chlorophyll content and andrographolide content (Table 32).

Plants grown under no mulch in shaded condition recorded higher chlorophyll content (1.21 mg g^{-1}) at 30 DAP and was on par with black polythene mulched plants in open condition. Minimum chlorophyll content was obtained in paddy straw mulch under shaded condition (0.75mg g^{-1}). At 60 DAP, plants in no mulch condition under shade recorded highest chlorophyll content (2.03 mg g^{-1}) whereas planting in no mulch condition in open recorded lower chlorophyll content (1.42 mg g^{-1}) which was on par

Table 30. Interaction effect of growing condition and mulching on soil temperature at 10 cm depth

Treatments	Soil temperature (°C)																			
	Week1		Week 2		Week 3		Week 4		Week 5		Week 6		Week 7		Week 8		Week 9		Week 10	
	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S
No mulch	27.5	25.6	26.7	25.2	27.4	25.6	27.4	25.4	26.4	25.1	26.9	25.2	27.3	25.6	27.2	25.3	26.7	24.7	27.1	25.4
Paddy straw	27.5	25.7	26.7	25.2	27.5	25.6	27.4	25.4	26.4	25.1	26.9	25.2	27.3	25.6	27.1	25.3	26.7	24.7	27.1	25.4
Black polythene	29.5	27.3	29.0	27.3	28.1	27.4	29.5	27.4	28.5	27.1	29.1	27.1	29.5	27.5	29.3	27.2	28.7	27.0	29.4	27.3
CD (0.05)	0.07		0.06		0.15		NS		NS		0.07		0.08		0.12		0.08		0.05	

Treatments	Soil temperature (°C)																			
	Week11		Week 12		Week 13		Week 14		Week 15		Week 16		Week 17		Week 18		Week 19		Week 20	
	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S
No mulch	27.2	25.2	27.1	25.1	26.6	25.0	26.8	25.2	26.9	25.2	26.4	24.8	26.6	24.9	26.3	25.2	26.7	25.6	26.4	25.2
Paddy straw	27.2	25.2	27.1	25.1	26.6	25.0	26.8	25.2	27.0	25.2	26.4	24.8	26.6	24.9	26.3	25.3	26.7	25.6	26.5	25.2
Black polythene	29.3	27.1	29.3	27.1	28.7	27.1	29.0	27.2	29.3	27.2	28.5	26.9	28.6	27.0	28.3	27.1	28.5	27.3	28.4	27.2
CD (0.05)	NS		0.02		0.03		0.03		0.03		NS		0.02		0.01		0.03		0.03	

Table 31. Interaction effect of growing condition and mulching on soil moisture at 15 cm depth

Treatments	Soil moisture (%)									
	14 DAP		28 DAP		42 DAP		56 DAP		60 DAP	
	O	S	O	S	O	S	O	S	O	S
No mulch	13.85	15.41	14.01	14.93	56.95	56.67	12.57	13.44	35.15	35.87
Paddy straw	14.49	16.68	14.60	16.05	57.60	58.10	13.85	14.44	35.71	36.99
Black polythene	16.00	18.41	15.43	17.17	58.22	58.93	14.45	15.99	36.78	38.01
CD (0.05)	0.02		0.01		0.03		0.02		0.02	

Treatments	Soil moisture (%)									
	74 DAP		88 DAP		102 DAP		116 DAP		130 DAP	
	O	S	O	S	O	S	O	S	O	S
No mulch	13.18	13.65	12.35	12.82	12.37	13.60	11.79	12.88	11.95	12.60
Paddy straw	13.72	15.44	13.57	14.59	12.75	14.08	12.56	13.60	12.35	13.54
Black polythene	15.63	16.67	14.99	16.43	14.30	15.86	13.65	15.31	13.87	15.14
CD (0.05)	0.02		0.03		0.02		0.02		0.15	

with plants in paddy straw mulch in open and shaded condition with 1.51 mg g^{-1} and 1.44 mg g^{-1} respectively. At harvest, with chlorophyll content of 2.57 mg g^{-1}, paddy straw mulch under 50 per cent shade found to be the maximum and minimum chlorophyll content (1.49 mg g^{-1}) was obtained from the plants without any mulch under open condition which was on par with paddy straw mulching in open condition (1.59 mg g^{-1}).

Andrographolide content (%)

At harvest, crops planted in paddy straw mulch under shaded condition recorded higher andrographolide content with 1.11 % and a minimum of 0.92 % was noticed from crops planted without mulch in open condition (Table 32).

Crop growth rate

Table 33. represents the interaction effect of growing condition and mulching on crop growth rate and relative growth rate. At 30 to 60 DAP crop growth rate showed significantly higher value in black polythene in open condition (2.12 g m^{-2} day^{-1}) and lower value was recorded in no mulch condition under shade. At 60 DAP to harvest, black polythene sheet in open condition (10.05 g m^{-2} day^{-1}) and paddy straw mulch in open condition recorded lower crop growth rates.

Relative growth rate

From the data in Table 33. it is clear that significantly higher RGR was recorded from black polythene mulch under open condition (0.079 g g^{-1} day^{-1}) which was on par with May planting in shade (0.058 g g^{-1} day^{-1}). Lower RGR was recorded from May planting in open condition (0.058 g g^{-1} day^{-1}).

Table 32. Interaction effect of growing condition and mulching on total chlorophyll content (mg g^{-1}) at different growth stages and andrographolide (%)

Treatments	Total chlorophyll (mg g^{-1})						Andrographolide (%)	
	30 DAP		60 DAP		Harvest		At harvest	
	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade
No mulch	1.16	1.21	1.42	2.03	1.49	1.94	0.92	1.02
Paddy straw	0.89	0.75	1.51	1.44	1.59	2.57	1.00	1.11
Black polythene	1.14	1.02	1.77	1.69	1.75	2.17	0.96	1.01
CD (0.05)	0.11		0.15		0.16		0.02	

Table 33. Interaction effect of growing condition and mulching on crop growth rate, relative growth rate and andrographolide at different growth stages

Treatments	CGR ((g m^{-2}day^{-1})				RGR (g g^{-1}day^{-1})			
	30 - 60 DAP		60 DAP- harvest		30 - 60 DAP		60 DAP- harvest	
	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade
No mulch	1.27	1.00	7.32	8.87	0.077	0.058	0.031	0.034
Paddy straw	1.28	1.38	7.01	7.25	0.073	0.068	0.032	0.030
Black polythene	2.12	2.10	10.05	7.93	0.079	0.069	0.030	0.027
CD (0.05)	0.16		0.59		0.005		0.001	

4.2.2. e Observations on weeds

Weed density

Interaction effect of growing condition and mulching on weed density, weed dry weight are given in Table 34. At 30 DAP, data was non significant. At 60 DAP, weed count was significant and the higher weed density was noticed in no mulch condition under shaded condition (272.33 no.m^{-2}) and black polythene mulch under shaded condition recorded lower weed density (7 no.m^{-2}).

Weed dry weight

Interaction effect of growing condition and mulching had significant influence on weed dry weight at 30 DAP and 60 DAP. At 30 DAP, higher weed dry weight was noticed in no mulch open condition (117.47 g m^{-2}) whereas lower weed dry weight was recorded in black polythene mulch under open condition (10.78 g m^{-2}).

4.2.3. Interaction between planting dates and mulching

4.2.3. a Plant height at 30, 60 DAP and at harvest

Data on interaction between planting dates and mulching on plant height, number of branches and days to first flowering are depicted in Table 35. At 30 DAP, interaction was found to be non significant. However at 60 DAP and at harvest significant variations were seen. At 60 DAP, highest plant height was recorded in crops planted in July under black polythene sheet (33.32 cm) and lower plant height (8.29 cm) was observed in May planted crops under no mulch which was on par with May planted crops under paddy straw mulch (8.46 cm). At harvest, higher plant height of 82.5 cm was recorded with crops planted in July under no mulch condition which was on par with July planting with black polythene sheet (81.20 cm). Lower plant height was observed in crops planted in June under no mulch condition (63.10 cm).

Table 34. Interaction effect of growing condition and mulching on weed density and weed dry weight

Treatment	Weed density (no.m^{-2})				Weed dry weight (g m^{-2})			
	30 DAP		60 DAP		30 DAP		60 DAP	
	Open	50% shade	Open	50% shade	Open	50% shade	Open	50% shade
No mulch	19.71** (400.58)	18.50 (341.75)	14.05 (217.00)	16.38 (272.33)	10.71 (117.47)	9.12 (82.63)	8.78 (78.09)	7.94 (64.43)
Paddy straw	13.79 (192.50)	13.21 (176.25)	12.00 (153.50)	11.77 (140.50)	8.21 (67.78)	7.51 (55.70)	7.47 (55.02)	6.07 (36.02)
Black polythene	3.77 (19.00)	3.41 (13.83)	3.92 (14.83)	2.50 (7.00)	3.09 (10.78)	3.98 (18.37)	3.05 (8.40)	2.93 (8.93)
CD (0.05)	NS		1.08		0.67		0.29	

** $\sqrt{x+0.5}$ transformed values, original values are given in parenthesis

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No. of branches per plant at 30 DAP, 60 DAP and at harvest

At 30 DAP, no branching was observed and at 60 DAP, significant difference was observed with more number of branches recorded in August planting under black polythene mulch (7.72)which was on par with June planting in paddy straw mulch (7.40), June planting in black polythene mulch (7.6) and July planting in black polythene mulch (7.67). Minimum number of branches was noticed in crops planted in May under no mulch condition (4.60). At harvest, the data were non significant.

Days to first flowering

Interaction between planting dates and mulching was found to be non significant on days to first flowering.

Fresh biomass yield at 30, 60 DAP and at harvest

Data on interaction between planting dates and mulching on fresh biomass yield and total yield are depicted in Table 36. At 30 DAP, data was non significant, however it was significant in 60 DAP and harvest. At 60 DAP, highest biomass yield was recorded in May planting with black polythene mulch (20.27 g $plant^{-1}$) and was on par with June planting with black polythene mulch (19.80 g $plant^{-1}$). Crop planted in May in no mulch recorded lowest biomass yield (7.37 g $plant^{-1}$) which was on par with July and August planting with 8.93 g $plant^{-1}$and 8.14 g $plant^{-1}$ respectively under no mulch condition.

At harvest, maximum biomass yield (166.49 g $plant^{-1}$) was obtained from May planted crops in black polythene mulch and a minimum of 51.76 g $plant^{-1}$ recorded in July planting without any mulching.

Table 35. Interaction effect of planting dates and mulching on plant height, number of branches and days to first flowering of kiriyath at different growth stages

	Plant height (cm)									No. of branches						Days to first flowering		
	30 DAP			60 DAP			Harvest			60 DAP			Harvest					
	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene
15-May	5.32	5.81	6.39	8.29	8.46	14.05	67.6	64.6	67.7	4.6	4.9	6.83	21.02	21.65	24.65	108.75	108	108.25
15-Jun	5.07	6.11	6.30	17.96	18.87	21.81	63.1	65.7	65.5	6.32	7.4	7.6	20.87	21.37	21.22	108	108.5	109.5
15-Jul	4.64	5.67	6.68	27.05	26.51	33.32	82.5	75.6	81.2	6.27	6.59	7.67	19.47	19.53	22.37	120	116	118.75
15-Aug	4.80	5.19	6.77	25.76	26.32	28.92	62.7	65.4	69.9	6.27	6.38	7.72	19.68	20.17	22.87	114.5	115.25	116
CD (0.05)	NS			1.40			4.40			0.62			NS			NS		

Table 36. Interaction effect of planting dates and mulching on biomass yield and total yield of kiriyath at different growth stages

Treatments	Biomass Yield (g $plant^{-1}$)									Total Yield (kg ha^{-1})		
	30 DAP			60 DAP			Harvest					
	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene
15-May	1.24	1.46	1.99	7.37	9.73	20.27	120.55	144.75	166.49	10,457	12,958	15,204
15-Jun	1.43	1.40	2.10	10.88	12.30	19.80	90.60	94.14	146.82	7,362	7,728	13,171
15-Jul	1.38	1.38	2.02	8.93	10.00	13.08	51.76	69.78	106.65	3,349	5,211	9,021
15-Aug	1.40	1.38	1.81	8.14	10.00	13.65	72.15	85.45	131.60	5,456	6,830	11,599
CD (0.05)	NS			1.98			11.07			1144		

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Total yield

The combined effect of planting dates and mulching on total yield was found significant with maximum yield (15,204 kg ha^{-1}) obtained from May planting in black polythene mulch. The next best interaction was between May planting and paddy straw mulching (12,958 kg ha^{-1}). Lowest yield was recorded in July planting under no mulch condition (3,349 kg ha^{-1}).

4.2.3. b Soil analysis

Soil pH

The interaction between different dates of planting and mulching on soil pH was non significant (Table 37).

Organic carbon

A non significant interaction was observed between different dates of planting and mulching on soil pH.

Available nitrogen

The interaction effect of dates of planting and mulching did not had significant influence on the available nitrogen content (Table 37).

Available phosphorus

Available phosphorus did not showed any significant interaction between planting dates and mulching (Table 37).

Table 37. Interaction effect of planting dates and mulching on pH, organic carbon and available N, P and K

Treatments	pH			Organic carbon (%)			Available N ($kg\ ha^{-1}$)			Available P ($kg\ ha^{-1}$)			Available K ($kg\ ha^{-1}$)		
	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene
15-May	5.55	5.30	5.25	2.09	2.04	2.04	249.18	244.14	248.74	9.95	10.46	10.40	144.04	168.79	162.72
15-Jun	5.45	5.46	5.41	2.14	2.04	2.13	244.78	243.93	245.85	10.45	9.89	10.34	130.89	182.97	180.60
15-Jul	5.38	5.29	5.15	1.90	1.80	2.30	247.54	247.92	246.55	10.43	10.71	9.93	162.80	169.64	158.73
15-Aug	5.18	5.25	5.24	2.14	1.72	1.90	243.12	246.67	244.80	10.07	9.73	10.04	146.37	230.93	152.44
CD (0.05)	NS			NS			NS			NS			0.48		

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Available potassium

Significantly higher available K content (230.93 kg ha^{-1}) was obtained from the interaction between August planting and paddy straw mulch (Table 37). Planting in June without any mulch recorded lower soil K content after the experiment (130.89 kg ha^{-1}).

4.2.3. c Micrometeorological observations

Soil temperature at 10 cm depth

Table 38. shows the interaction effect of planting dates and mulching on soil temperature. The soil temperature in this treatment combination ranged from 25.1 °C to 29.2 °C. Higher soil temperature was recorded in 3rd week of July planted plots in black polythene mulch. Week 9 of July planted plots recorded lower soil temperature under no mulch and paddy straw mulch in open condition.

Soil moisture at 15 cm depth

Interaction effect of planting dates and mulching on soil moisture (Table 39) showed that interaction had a significant influence on soil moisture in all stages. Soil moisture content of 100 per cent was observed at 42 DAP in May planting, 60 DAP in July planting and 42 DAP in August planting under both mulched and no mulched plots. Lower soil moisture content (11.09 %) was observed at 130 DAP in August planted plots under paddy straw mulch.

Table 38. Interaction effect of planting dates and mulching on soil temperature

Treatments	Week1			Week 2			Week 3			Week 4			Week 5			Week 6		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
May	27.3	27.4	29.1	25.9	25.9	27.8	25.8	25.8	25.0	26.8	26.8	28.7	25.7	25.7	27.8	26.3	26.3	28.3
Jun	26.8	26.8	28.7	25.7	25.6	27.8	26.3	26.3	28.3	26.1	26.1	28.0	25.8	25.8	27.7	26.0	26.0	28.4
Jul	25.8	25.8	27.7	26.0	25.9	28.5	27.3	27.3	29.2	26.6	26.6	28.7	26.0	26.0	28.2	26.2	26.2	28.0
Aug	26.3	26.3	28.0	26.4	26.4	28.5	26.7	26.7	28.6	26.0	26.0	28.2	25.5	25.5	27.5	25.7	25.7	27.7
CD (0.05)	0.11			0.09			0.22			0.11			0.10			0.10		

Treatments	Week7			Week 8			Week 9			Week 10			Week 11			Week 12			Week13		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
May	26.2	26.2	28.3	25.8	25.7	27.7	26.0	26.0	28.5	27.3	27.2	29.2	26.6	26.6	28.7	26.0	26.0	28.2	26.1	26.2	28.1
Jun	27.2	27.2	29.2	26.6	26.6	28.6	26.0	26.0	28.2	26.2	26.1	28.1	26.8	26.8	28.7	26.6	26.6	28.6	25.2	25.2	27.3
Jul	26.8	26.8	28.6	26.6	26.6	28.6	25.1	25.1	27.2	25.9	25.9	28.1	25.5	25.5	27.1	26.0	26.0	28.1	25.9	25.9	28.0
Aug	25.6	25.6	27.8	26.0	25.9	28.0	25.7	25.7	27.6	25.6	25.6	27.9	25.8	25.8	28.3	25.7	25.7	28.0	26.1	26.2	28.2
CD (0.05)	0.11			NS			0.11			0.07			NS			0.03			0.04		

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Treatments	Week 14			Week 15			Week 16			Week 17			Week 18			Week 19			Week 20		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
May	26.1	26.2	28.1	26.8	26.8	28.7	26.6	26.6	28.6	25.2	25.2	27.3	26.0	26.0	28.1	25.2	25.3	27.2	26.1	26.1	28.1
Jun	25.2	25.2	27.3	26.0	26.0	28.1	25.5	25.5	27.6	26.0	26.1	28.1	25.9	25.9	28.0	25.9	26.0	27.8	25.9	26.0	28.1
Jul	25.9	25.9	28.0	25.4	25.5	27.6	26.0	26.0	28.6	25.5	25.5	27.9	25.9	25.9	27.7	25.8	25.8	27.7	25.4	25.5	27.4
Aug	26.1	26.2	28.2	25.9	25.9	28.0	26.2	26.2	28.2	25.6	25.6	27.3	25.3	25.3	27.4	26.1	26.1	28.1	25.8	25.8	27.8
CD (0.05)	0.04			0.04			0.04			0.16			0.03			0.02			0.07		

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Table 39. Interaction effect of planting dates and mulching on soil moisture at 15 cm depth

Treatments	14 DAP			28 DAP			42 DAP			56 DAP			60 DAP		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
May	13.54	14.11	15.71	13.58	14.52	15.31	100.01	100.02	100.05	11.91	14.47	14.81	15.32	16.79	18.81
Jun	14.65	15.94	16.79	15.09	15.86	17.67	14.81	16.58	19.01	12.85	13.56	14.05	13.20	14.43	15.14
Jul	15.23	16.78	18.98	15.72	16.85	17.22	12.41	14.78	15.22	14.05	13.99	16.54	100.01	100.02	100.06
Aug	15.11	15.52	17.34	13.48	14.08	14.98	100.01	100.02	100.03	13.22	14.57	15.48	13.52	14.18	15.57
CD (0.05)	0.03			0.02			0.05			0.03			0.03		

Treatments	74 DAP			88 DAP			102 DAP			116 DAP			130 DAP		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
May	12.10	13.99	14.90	11.92	13.77	14.80	13.47	13.61	14.67	13.57	13.72	15.63	12.97	13.88	14.61
Jun	14.08	14.53	15.93	14.14	15.48	18.32	12.92	13.23	15.69	12.65	13.39	14.68	13.05	13.31	15.41
Jul	14.34	15.88	18.57	12.58	13.38	15.49	12.95	13.00	14.70	11.95	13.29	14.12	11.85	13.49	14.36
Aug	13.15	13.92	15.20	11.71	13.70	14.22	12.61	13.80	15.26	11.17	11.92	13.47	11.23	11.09	13.63
CD (0.05)	0.02			0.04			0.03			0.03			0.21		

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4.2.3. d Physiological, chemical and biochemical observations

Total chlorophyll content 30 DAP, 60 DAP and at harvest

Data on interaction effect of planting dates and mulching on total chlorophyll and andrographolide content are given in Table 40. At 30 DAP, significantly highest total chlorophyll content (1.67 mg g^{-1}) was observed in the crop planted in August with black polythene mulch whereas minimum was recorded in July planting with black polythene mulch (0.54 mg g^{-1}) and was on par with July planting with paddy straw mulch.

At 60 DAP, June planted crop without any mulch showed significant highest chlorophyll content (2.57 mg g^{-1}) whereas minimum (1.25 mg g^{-1}) was recorded by the crop planted in July without any mulch. At harvest, significantly higher chlorophyll content was recorded from June planting in paddy straw mulch (2.57 mg g^{-1}) and was on par with no mulch (2.08 mg g^{-1}), paddy straw (2.52 mg g^{-1}) and black polythene mulch (2.06 mg g^{-1}) in May planting and also crop planted in June in black polythene (2.26 mg g^{-1}). Lower value (1.37 mg g^{-1}) was observed in July planting in paddy straw mulch (1.57 mg g^{-1}) and August planting without any mulch (1.56 mg g^{-1}).

Andrographolide content (%)

Interaction between dates of planting and mulching had significant influence on andrographolide content at harvest. Andrographolide content was found maximum with crops planted either on 15th July or 15th August with paddy straw mulch (1.09 %) and minimum andrographolide content was recorded in May planting without mulching in open condition (0.93 %).

Crop growth rate

Interaction effect of planting date and mulching on crop growth rate and relative growth rate are depicted in Table 41. At 30 to 60 DAP, highest CGR was recorded in June planting under black polythene mulch (3.06 g m^{-2} day^{-1}) whereas lower CGR was found with May planting without any mulch (1.14 g m^{-2} day^{-1}). At 60 DAP to harvest, June planting without any mulching recorded higher CGR value (12.84 g m^{-2} day^{-1}) and lower CGR was observed in July planting without any mulching (4.19 g m^{-2} day^{-1}).

Relative growth rate

At 30 DAP to 60 DAP, higher RGR was recorded with June planting and black polythene mulching (0.084 g g^{-1} day^{-1}). Lower RGR was recorded from August planting under no mulch Significantly higher RGR of 0.036 g g^{-1} day^{-1} was recorded in August planting under no mulch condition at 60 DAP to harvest and was on par with May and June planting without mulching (0.035 g g^{-1} day^{-1}), paddy straw mulching (0.034 g g^{-1} day^{-1}). Lower RGR was recorded from June planting with black polythene mulch (0.026 g g^{-1} day^{-1}) and July planting in no mulch condition (0.026 g g^{-1} day^{-1}).

4.2.3. e Observations on weeds

Weed density

Combined effect of planting dates and mulching on weed count, weed dry weight are given in Table 42. At 30 DAP, significantly higher weed density was recorded in June planting without mulching (457.67 no.m^{-2}) and was on par with May planting without mulching (400.50 no.m^{-2}). Lower weed density was observed in July planting in black polythene mulch (5.33 no.m^{-2}) which was on par with August planting in black polythene mulch (6.67 no.m^{-2}).

At 60 DAP, higher weed density was recorded in June planting without mulching (361 no.m^{-2}) and lower weed density was noticed in June planting under black polythene mulch (6.33 no.m^{-2}) which was on par with all other planting dates in black polythene mulch.

Weed dry weight

Weed dry weight showed significantly higher value in May planting without mulching (125.17 g m^{-2}) at 30 DAP which was on par with June planting in no mulch condition (113.67 g m^{-2}). July planting in black polythene mulch (7.93 g m^{-2}) recorded to have minimum weed dry weight which was on par with August planting in black polythene mulch (6.10 g m^{-2}).

Table 40. Interaction effect of planting dates and mulching on total chlorophyll content and andrographolide (%) at different growth stages

Treatments	Total chlorophyll content (mg g^{-1})									Andrographolide (%)		
	30 DAP			60 DAP			Harvest			Harvest		
	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene
15-May	1.13	0.93	1.27	1.68	1.80	1.77	2.08	2.52	2.06	0.93	1.05	1.03
15-Jun	1.16	0.73	0.85	2.57	1.53	1.87	1.81	2.57	2.26	0.97	0.99	0.94
15-Jul	1.20	0.56	0.54	1.25	1.30	1.53	1.37	1.57	1.63	0.99	1.09	0.95
15-Aug	1.24	1.06	1.67	1.40	1.27	1.75	1.56	1.67	1.9	1.01	1.09	1.03
CD (0.05)	0.14			0.21			0.22			0.03		

Table 41. Interaction effect of planting dates and mulching on crop growth rate, relative growth rate at different growth stages

Treatments	CGR (g $m^{-2}day^{-1}$)						RGR (g $g^{-1}day^{-1}$)					
	30- 60 DAP			60 DAP- harvest			30- 60 DAP			60 DAP- harvest		
	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene
15-May	1.14	1.28	2.54	8.75	9.44	9.31	0.072	0.066	0.080	0.035	0.034	0.027
15-Jun	1.53	1.67	3.06	12.84	6.73	10.64	0.075	0.077	0.084	0.035	0.028	0.026
15-Jul	1.24	1.20	1.37	4.19	5.31	8.08	0.071	0.069	0.064	0.026	0.031	0.031
15-Aug	0.64	1.17	1.48	6.60	7.03	7.94	0.051	0.069	0.068	0.036	0.032	0.030
CD (0.05)	0.22			0.83			0.007			0.002		

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Table 42. Interaction effect of planting dates and mulching on weed density and weed dry weight at different growth stages

Treatment	Weed density (no.m^{-2})						Weed dry weight (gm-2)					
	30 DAP			60 DAP			30 DAP			60 DAP		
	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene	No mulch	Paddy straw	Black polythene
15-May	20.01** (400.50)	13.04 (171.00)	4.65 (21.00)	15.26 (241.00)	9.21 (86.33)	3.06 (8.67)	11.17 (125.17)	8.74 (76.20)	4.52 (20.55)	9.01 (81.73)	6.72 (44.70)	3.04 (8.25)
15-Jun	21.19 (457.67)	15.50 (239.50)	5.32 (32.67)	18.89 (361.00)	15.26 (236.00)	2.57 (6.33)	10.62 (113.67)	7.83 (60.50)	4.95 (23.70)	8.59 (74.90)	6.78 (46.54)	1.93 (3.28)
15-Jul	18.48 (341.50)	11.64 (135.00)	2.03 (5.33)	11.28 (138.67)	11.14 (123.67)	3.24 (12.00)	9.64 (94.15)	8.05 (64.87)	2.26 (7.93)	6.61 (42.75)	6.29 (38.67)	3.18 (9.17)
15-Aug	16.75 (285.00)	13.82 (192.00)	2.37 (6.67)	15.43 (238.00)	11.94 (142.00)	3.98 (16.67)	8.23 (67.20)	6.81 (45.40)	2.42 (6.10)	9.23 (85.65)	7.27 (52.17)	3.82 (13.94)
CD (0.05)	1.36			1.53			0.94			0.41		

** $\sqrt{x+0.5}$ transformed values, original values are given in parenthesis

At 60 DAP, August planting without any mulching recorded significantly higher weed dry weight (85.65 g m^{-2}) which was on par with May planting without mulching (81.73 g m^{-2}). Lower weed dry weight was recorded in June planting under black polythene mulch (3.28g m^{-2}).

4.3. Three factor interactions

4.3.1. Biometric observations

Interaction between growing condition, planting dates and mulching

Plant height at 30, 60 DAP and at harvest

Combined effect of growing condition, planting dates and mulching on plant height, number of branches and days to first flowering are depicted in Table 43. At 30 DAP, the data was non significant. At 60 DAP, interaction had significant influence on plant height with maximum plant height recorded in August planting under shade in black polythene sheet (37.35 cm) and was on par with July planting under shade in black polythene sheet (37.27 cm).Crops planted in May without any mulch in open condition recorded lower plant height (7.04 cm) which was on par with May planted crops in paddy straw mulch under open condition (7.06 cm). At harvest, interaction was found to be non significant.

No. of branches per plant at 30 DAP, 60 DAP and at harvest

At 30 DAP, no branching was observed and at 60 DAP combined effect of growing condition, planting dates and mulching was found to be significant with the highest number of branches (7.8) in crops planted in June in black polythene sheet and August in black polythene sheet under open condition and was on par with the May planting in black polythene sheet under 50 per cent shade (7.53), June planting with paddy straw mulch in both open (7.2) and shaded condition (7.6), July planting with paddy straw mulch in open condition (7.05), July planting with black polythene sheet under shaded condition (7.33) and August planting with black polythene sheet under 50 per cent shaded condition (7.63).The lowest number of branches (4.2) was recorded in May planted crops under shade without any mulching. At harvest, combined effect of growing condition, planting dates and mulching was non significant.

Days to first flowering

Interaction between growing condition, planting dates and mulching was found to be non significant on days to first flowering (Table 44).

Fresh biomass yield at 30, 60 DAP and at harvest

Combined effect of growing condition, planting dates and mulching on fresh biomass yield and total yield are depicted in Table 45. At 30 DAP, the interaction had no influence on fresh biomass yield. However, at 60 DAP and at harvest significant difference was observed. At 60 DAP, maximum biomass was recorded in May planting with black polythene sheet under 50 per cent shade (22 g $plant^{-1}$) and was on par with June and August planting with black polythene sheet (20.50 g $plant^{-1}$ and 19.30 g $plant^{-1}$ respectively) under shaded condition. A minimum of 4.54 g $plant^{-1}$ was recorded in July planting without any mulch in open condition and was on par with May planting without mulch in shaded condition (4.84 g $plant^{-1}$).

At harvest, maximum biomass was recorded in May planting with black polythene sheet under 50 per cent shade (171.03 g $plant^{-1}$) and minimum biomass yield (35 g $plant^{-1}$) obtained from crop planted in July with paddy straw in open condition and was on par with July planting with paddy straw in open condition(42.63 g $plant^{-1}$).

Table 43. Interaction effect of growing condition, planting dates and mulching on plant height and number of branches of kiriyath at different growth stages

Treatment	Plant height (cm)						Number of branches			
	30 DAP		60 DAP		Harvest		60 DAP		Harvest	
	Open	50% Shade	Open	50% Shade	Open	50% Shade	Open	50% Shade	Open	50% Shade
May x No mulch	4.37	6.27	7.04	9.54	58.35	76.87	5.00	4.20	19.63	22.4
May x Paddy straw	4.63	6.99	7.06	9.85	53.35	75.85	5.00	4.80	20.7	22.6
May x Black polythene	4.93	7.85	9.35	18.75	54.33	81.08	6.13	7.53	23.5	25.8
June x No mulch	3.87	6.27	13.96	21.97	57.47	68.70	6.47	6.17	19.6	22.13
June x Paddy straw	4.74	7.48	13.93	23.81	55.60	75.80	7.20	7.60	19.27	23.47
June x Black polythene	5.03	7.57	18.11	25.52	58.60	72.47	7.80	7.40	20.6	21.83
July x No mulch	3.95	5.33	20.16	33.94	64.20	100.80	6.14	6.40	17.93	21
July x Paddy straw	4.88	6.47	16.95	36.08	52.13	99.07	7.05	6.13	16.13	22.93
July x Black polythene	5.13	8.23	29.37	37.27	63.53	98.80	8.00	7.33	19.53	25.2
Aug x No mulch	3.71	5.88	17.57	33.94	54.18	71.16	5.72	6.83	18.38	20.98
Aug x Paddy straw	3.71	6.67	18.65	33.99	56.73	73.97	6.60	6.15	19.24	21.1
Aug x Black polythene	4.60	8.95	20.49	37.35	58.13	81.75	7.8	7.63	20.87	24.87
CD (0.05)	NS		1.97		NS		0.88		NS	

Table 44. Interaction effect of growing condition, planting dates and mulching on days to first flowering, biomass production and total biomass yield

Treatment	Days to first flowering		Biomass production (g plant^{-1})						Total biomass (kg/ha)	
			30 DAP		60 DAP		Harvest			
	Open	50% Shade	Open	50% Shade	Open	50% Shade	Open	50% Shade	Open	50% Shade
May x No mulch	109.5	108	0.72	1.76	9.91	4.84	124.40	116.70	10,855	10,059
May x Paddy straw	109	107	1.00	1.92	11.51	7.94	148.10	141.40	13,304	12,611
May x Black polythene	109	107.5	1.22	2.75	18.53	22.00	161.95	171.03	14,735	15,673
June x No mulch	107.5	108.5	1.05	1.80	10.77	11.00	66.40	114.80	4,861	9,863
June x Paddy straw	109.5	107.5	0.99	1.82	13.10	11.50	74.13	114.15	5,660	9,796
June x Black polythene	111	108	1.54	2.66	19.09	20.50	135.53	158.10	12,005	14,337
July x No mulch	112.5	127.5	1.09	1.67	7.53	10.33	42.63	60.90	2,405	4,293
July x Paddy straw	109.5	122.5	1.09	1.67	4.50	15.50	35.00	104.57	1,617	8,805
July x Black polythene	111	126.5	1.49	2.55	7.50	18.67	94.90	118.40	7,806	10,235
Aug x No mulch	106.5	122.5	1.06	1.74	7.50	8.79	59.20	85.10	4,117	6,794
Aug x Paddy straw	108.5	122	0.86	1.90	6.78	13.22	73.83	97.07	5,629	8,030
Aug x Black polythene	108	124	1.17	2.44	8.00	19.30	149.60	113.60	9,739	13,459
CD (0.05)	NS		NS		2.81		15.65		1,618	

Total yield

Interaction effect of growing condition, planting dates and mulching on total yield was significant with highest yield (15,673 kg ha^{-1}) recorded in crops planted in May with black polythene sheet under 50 per cent shaded condition which was on par with June planting with black polythene sheet under 50 per cent shaded condition (14,337 kg ha^{-1}). Lowest yield was obtained from July planting without any mulch in open condition (1,617 kg ha^{-1}) and was on par with July planting without any mulch in open condition (2,405 kg ha^{-1}).

4.3.2. Soil analysis

Interaction between growing condition, planting dates and mulching

Combined effect of growing condition, planting dates and mulching on soil pH, organic carbon, available N, P and K are depicted in Table 45.

Soil pH

Combined effect of growing condition, planting dates and mulching on soil pH was found non significant.

Organic carbon

Data on combined effect of growing condition, planting dates and mulching on organic carbon was found non significant.

Available nitrogen

Interaction between growing condition, planting dates and mulching on soil available nitrogen is non significant.

Available phosphorus

Interaction effect of growing condition and planting dates could not bring any significant effect on available phosphorus content of soil.

Available potassium

Available K content in soil after experiment was found significantly higher (239.11 kg ha^{-1}) in August planting in paddy straw mulch under shaded condition and lower K content was recorded in August planting with black polythene sheet under shaded condition (120.99 kg ha^{-1}).

4.3.1. Micrometeorological observations

Soil temperature at 10 cm depth

Soil temperature was influenced by the combined effect of all the treatments and found significant in most of the stages. Higher soil temperature (30.6 °C) was noticed in 7^{th} week of June planted and 10^{th} week of May planted plots under black polythene sheet in open condition whereas lower soil temperature (24.4 °C) was experienced in 13^{th} week of June planting and 9^{th} week of July in no mulch and paddy straw mulch under shaded condition (Table 46).

Soil moisture at 15 cm depth

Combined effect of growing condition, planting dates and mulching showed significant influence on soil moisture. Soil moisture content was observed 100% at 42 DAP in May planting, 60 DAP in July planting and 42 DAP in August planting both under open and shaded condition under all mulching condition. Lower soil moisture content was recorded 130 DAP in August planted plots under paddy straw mulch in open condition (Table 47)

Table 45. Interaction effect of growing condition, planting dates and mulching pH, organic carbon and available N, P, K of soil

Treatment	pH		Organic carbon (%)		Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
	Open	50% Shade	Open	50% Shade	Open	50% Shade	Open	50% Shade	Open	50% Shade
May x No mulch	5.23	5.27	1.84	2.34	251.80	246.56	9.915	9.98	155.50	152.58
May x Paddy straw	5.35	5.24	2.09	1.99	245.42	242.86	10.46	10.46	186.49	181.09
May x Black polythene	5.17	5.03	2.14	1.94	245.48	252.00	10.13	10.68	128.30	127.15
June x No mulch	5.25	5.25	1.90	2.39	241.65	247.92	10.56	10.33	153.18	158.60
June x Paddy straw	5.21	5.31	1.78	2.29	242.80	245.07	9.115	10.66	191.48	184.46
June x Black polythene	5.15	5.18	2.25	2.00	242.53	249.17	10.08	10.61	130.94	130.27
July x No mulch	5.18	5.19	1.70	2.04	247.24	247.84	10.63	10.23	153.49	162.10
July x Paddy straw	5.27	5.12	1.65	1.95	252.54	243.31	11.06	10.37	190.22	189.06
July x Black polythene	5.19	5.11	2.41	2.24	243.12	249.99	10.07	9.78	126.71	130.75
Aug x No mulch	5.19	5.17	2.14	2.14	239.00	247.24	10.01	10.13	157.88	154.86
Aug x Paddy straw	5.25	5.24	1.59	1.85	245.17	248.17	9.35	10.12	182.75	189.11
Aug x Black polythene	5.14	5.13	1.90	1.90	238.00	251.60	10.08	10.01	123.89	130.99
CD (0.05)	NS		NS		NS		NS		0.69	

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Table 46. Interaction effect of growing condition, planting dates and mulching on soil temperature (°C)

Treatments	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		Week 7	
	O	S	O	S	O	S	O	S	O	S	O	S	O	S
May x No mulch	28.3	26.3	26.8	25.1	26.7	24.8	27.8	25.8	26.2	25.1	27.1	25.6	26.7	25.6
May x Paddy straw	28.3	26.4	26.7	25.0	26.7	24.8	27.7	25.8	26.2	25.1	27.1	25.6	26.7	25.6
May x Black polythene	30.3	27.8	28.8	26.8	28.2	26.8	29.8	27.7	28.6	27.0	29.2	27.4	29.1	27.5
June x No mulch	27.8	25.9	26.3	25.1	26.9	25.6	26.7	25.6	26.5	25.1	26.8	25.1	28.2	26.2
June x Paddy straw	27.7	25.8	26.3	25.0	27.2	25.5	26.7	25.6	26.5	25.1	26.8	25.1	28.2	26.2
June x Black polythene	29.8	27.7	28.6	27.0	29.2	27.4	28.6	27.5	28.6	26.8	29.2	27.7	30.6	27.8
July x No mulch	26.5	25.1	26.8	25.1	28.3	26.3	27.5	25.6	27.2	24.9	27.1	25.2	27.8	25.7
July x Paddy straw	26.5	25.1	26.9	25.0	28.2	26.4	27.6	25.6	27.2	24.8	27.1	25.2	27.8	25.7
July x Black polythene	28.6	26.8	29.2	27.8	30.5	27.8	29.9	27.5	29.2	27.2	29.3	26.8	29.7	27.6
Aug x No mulch	27.2	25.3	27.1	25.7	27.8	25.6	27.6	24.5	25.8	25.2	26.7	24.7	26.2	25.0
Aug x Paddy straw	27.2	25.3	27.1	25.8	27.8	25.7	27.6	24.5	25.9	25.2	26.7	24.7	26.2	25.0
Aug x Black polythene	29.3	26.8	29.3	27.6	29.7	27.5	29.7	26.7	27.7	27.3	28.9	26.6	28.5	27.1
CD (0.05)	0.15		0.12		0.30		0.16		0.13		0.14		0.15	

Treatments	Week 8		Week 9		Week 10		Week 11		Week 12		Week 13		Week 14	
	O	S	O	S	O	S	O	S	O	S	O	S	O	S
May x No mulch	26.4	25.1	26.9	25.1	28.2	26.3	27.6	25.7	27.2	24.9	27.0	25.3	27.9	25.8
May x Paddy straw	26.4	25.0	26.9	25.1	28.2	26.3	27.6	25.7	27.2	24.9	27.0	25.3	27.9	25.8
May x Black polythene	28.5	26.8	29.2	27.7	30.6	27.9	29.9	27.5	29.2	27.2	29.3	26.9	29.8	27.6
June x No mulch	27.5	25.6	27.2	24.8	27.1	25.3	27.9	25.8	27.6	25.7	25.9	24.4	26.8	25.2
June x Paddy straw	27.6	25.6	27.2	24.8	27.1	25.2	27.9	25.8	27.6	25.7	25.9	24.5	26.8	25.2
June x Black polythene	29.8	27.4	29.2	27.2	29.3	26.9	29.8	27.6	29.8	27.5	27.8	26.8	28.9	27.3
July x No mulch	27.6	25.6	25.8	24.4	26.7	25.2	26.3	24.8	27.0	25.0	26.9	24.9	26.3	24.6
July x Paddy straw	27.5	25.6	25.8	24.4	26.7	25.2	26.3	24.8	27.1	25.0	26.9	24.9	26.3	24.6
July x Black polythene	29.7	27.4	27.7	26.7	28.8	27.3	27.6	26.6	29.2	27.1	28.9	27.0	28.8	26.5
Aug x No mulch	27.1	24.8	26.8	24.6	26.3	24.8	27.2	24.5	26.6	24.9	26.8	25.5	26.4	25.3
Aug x Paddy straw	27.0	24.8	26.8	24.6	26.3	24.8	27.2	24.5	26.6	24.9	26.8	25.5	26.4	25.4
Aug x Black polythene	29.1	27.0	28.8	26.4	28.7	27.2	30.0	26.6	29.3	26.8	28.8	27.7	28.6	27.4
CD (0.05)	NS		0.15		0.10		NS		0.04		0.05		0.06	

Treatments	Week 15		Week 16		Week 17		Week 18		Week 19		Week 20	
	O	S	O	S	O	S	O	S	O	S	O	S
May x No mulch	27.6	25.7	25.9	24.5	26.8	25.2	25.8	24.7	26.8	25.3	26.8	25.4
May x Paddy straw	27.6	25.7	25.9	24.5	26.8	25.2	25.8	24.7	26.8	25.3	26.8	25.4
May x Black polythene	29.8	27.5	27.8	26.8	28.9	27.3	27.8	26.6	28.8	27.2	28.9	27.4
June x No mulch	26.3	24.7	27.0	25.1	26.9	24.9	26.4	25.4	26.5	25.6	26.9	25.0
June x Paddy straw	26.3	24.8	27.0	25.1	26.9	24.9	26.5	25.5	26.5	25.6	26.9	25.1
June x Black polythene	28.6	26.6	29.2	27.1	28.9	27.0	28.5	27.1	28.4	27.2	28.8	27.4
July x No mulch	27.2	24.9	26.6	24.5	26.9	24.9	26.3	25.2	26.0	25.1	25.9	25.0
July x Paddy straw	27.2	24.9	26.6	24.5	26.9	24.9	26.3	25.3	26.0	25.2	25.9	25.0
July x Black polythene	30.1	27.2	29.3	26.6	28.7	26.8	28.3	27.2	28.1	27.1	27.9	27.0
Aug x No mulch	26.7	25.6	26.1	25.0	25.7	24.8	26.6	25.6	27.4	26.4	26.3	25.3
Aug x Paddy straw	26.7	25.6	26.2	25.1	25.7	24.8	26.6	25.6	27.4	26.4	26.4	25.3
Aug x Black polythene	28.8	27.6	27.6	27.0	27.9	26.9	28.6	27.6	28.9	28.0	28.3	27.3
CD (0.05)	0.06		0.23		0.05		0.03		0.06		0.07	

Table 47. Interaction effect of growing condition, planting dates and mulching on soil moisture at 15 cm depth

Treatments	14 DAP		28 DAP		42 DAP		56 DAP		60 DAP	
	Open	Shade	Open	Shade	Open	Shade	Open	Shade	Open	Shade
May x No mulch	12.19	14.89	13.90	13.26	100	100	12.76	11.07	14.86	15.78
May x Paddy straw	12.87	15.35	14.49	14.55	100	100	14.40	14.55	15.78	17.80
May x Black polythene	15.50	15.93	15.18	15.45	100	100	14.46	15.16	17.59	20.03
June x No mulch	14.40	14.90	14.41	15.78	14.35	15.27	12.78	12.91	13.59	12.80
June x Paddy straw	14.51	17.36	14.44	17.27	15.68	17.48	13.65	13.47	13.90	14.95
June x Black polythene	15.40	18.17	15.32	20.03	17.65	20.37	13.91	14.19	14.51	15.78
July x No mulch	14.56	15.89	14.06	17.39	13.44	11.39	12.69	15.41	100	100
July x Paddy straw	15.89	17.67	14.90	18.80	14.68	14.88	13.69	14.29	100	100
July x Black polythene	17.69	20.27	15.95	18.49	15.16	15.28	15.27	17.81	100	100
Aug x No mulch	14.26	15.97	13.68	13.29	100	100	12.08	14.37	12.16	14.88
Aug x Paddy straw	14.69	16.36	14.57	13.59	100	100	13.67	15.47	13.15	15.20
Aug x Black polythene	15.41	19.27	15.27	14.70	100	100	14.17	16.80	14.99	16.16
CD (0.05)	0.04		0.02		0.07		0.04		0.04	

Treatments	74 DAP		88 DAP		102 DAP		116 DAP		130 DAP	
	Open	Shade	Open	Shade	Open	Shade	Open	Shade	Open	Shade
May x No mulch	12.14	12.06	11.56	11.03	12.58	14.36	12.66	14.49	13.66	12.29
May x Paddy straw	13.37	14.62	13.04	12.69	12.77	14.46	13.15	14.30	13.87	13.88
May x Black polythene	14.40	15.41	14.05	13.37	13.88	15.47	14.88	16.39	14.05	15.18
June x No mulch	13.66	14.50	13.88	14.39	12.50	13.35	12.16	13.15	13.16	12.95
June x Paddy straw	13.77	15.30	15.29	15.68	12.86	13.59	12.99	13.79	13.57	13.06
June x Black polythene	15.59	16.27	17.26	19.38	14.29	17.08	13.88	15.49	14.97	15.85
July x No mulch	13.80	14.87	12.95	12.22	12.89	13.02	12.26	11.65	11.03	12.67
July x Paddy straw	14.07	17.69	13.28	13.48	12.20	13.81	12.93	13.66	12.26	14.73
July x Black polythene	17.38	19.76	15.28	15.70	14.38	15.03	13.68	14.56	13.57	15.14
Aug x No mulch	13.14	13.16	11.03	12.39	11.53	13.68	10.09	12.25	9.98	12.49
Aug x Paddy straw	13.69	14.15	12.69	14.71	13.16	14.45	11.17	12.67	9.70	12.49
Aug x Black polythene	15.14	15.27	13.37	15.08	14.65	15.87	12.16	14.79	12.88	14.39
CD (0.05)	0.03		0.05		0.04		0.04		0.29	

4.3.4. Physiological, chemical and biochemical observations

Combined effect of growing condition, planting dates and mulching on total chlorophyll content and andrographolide (%) are depicted in Table 48. Interaction between growing condition, planting dates and mulching significantly influenced total chlorophyll content and andrographolide content.

Total chlorophyll content 30 DAP, 60 DAP and at harvest

At 30 DAP, significantly higher chlorophyll content (1.77 mg g^{-1}) was recorded in August planting in black polythene sheet under shaded condition and was on par with August planting with black polythene mulch in open condition (1.57 mg g^{-1}). Interaction between July planting, paddy straw mulch and shaded condition recorded lower chlorophyll content (0.37 mg g^{-1}). At 60 DAP, the significant maximum value was obtained with June planting without any mulch in shaded condition (3.45 mg g^{-1}) and minimum chlorophyll content (1.02 mg g^{-1}) with August planting without mulching in open condition. At harvest, higher chlorophyll content (3.26 mg g^{-1}) in June planting with paddy straw mulch under shade condition which was on par with May planting with paddy straw in shaded condition (3.14 mg g^{-1}). Lowest content was obtained from August planting in no mulch in open condition (1.28 mg g^{-1}).

Andrographolide content (%)

Maximum andrographolide content was found in the crop planted in July with paddy straw mulch under shaded condition (1.17 %) and was on par with August planting in paddy straw in 50 per cent shade (1.14 %). Minimum andrographolide content (0.87 %) was recorded with June planting without any mulch in open condition which was on par with planting 15th May without mulch in open condition (0.91 %) or June planting with black polythene mulch (0.89 %).

Table 48. Interaction effect of growing condition, planting dates and mulching on total chlorophyll content at different growth stages

Treatments	Total chlorophyll ($mg\ g^{-1}$)						Andrographolide (%)	
	30 DAP		60 DAP		Harvest		At harvest	
	Open	50% Shade	Open	50% Shade	Open	50% Shade	Open	50% Shade
May x No mulch	1.15	1.12	1.64	1.72	1.67	2.49	0.91	0.95
May x Paddy straw	0.99	0.87	1.83	1.77	1.90	3.14	0.99	1.10
May x Black polythene	1.53	1.00	1.69	1.84	2.09	2.04	0.96	1.09
June x No mulch	1.17	1.16	1.69	3.45	1.70	1.91	0.87	1.06
June x Paddy straw	0.90	0.55	1.93	1.13	1.89	3.26	0.95	1.02
June x Black polythene	0.87	0.83	2.28	1.46	2.09	2.42	0.89	0.99
July x No mulch	1.30	1.11	1.32	1.17	1.29	1.45	0.99	0.98
July x Paddy straw	0.76	0.37	1.11	1.48	1.29	1.84	1.00	1.17
July x Black polythene	0.59	0.49	1.54	1.52	1.34	1.92	0.94	0.95
Aug x No mulch	1.02	1.46	1.02	1.77	1.28	1.92	0.93	1.08
Aug x Paddy straw	0.91	1.22	1.16	1.38	1.29	2.05	1.04	1.14
Aug x Black polythene	1.57	1.77	1.56	1.94	1.49	2.31	1.05	1.01
CD (0.05)	0.20		0.30		0.31		0.05	

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Crop growth rate

Interaction effect of growing condition, planting dates and mulching on crop growth rate, is given in Table 49. At 30 to 60 DAP, highest CGR was observed in May planting under black polythene sheet in shaded condition (2.73 g m^{-2} day^{-1}) and lower CGR was recorded in July planting in paddy straw mulch in open condition (0.48 g m^{-2} day^{-1}). At 60 DAP to harvest, June planting without mulching under shade recorded higher CGR value whereas July planting without mulching under shade recorded lower CGR value (3.82 g m^{-2} day^{-1})

Relative growth rate

Relative growth rate was influenced significantly by the combined effects of treatments at different growth stages (Table 49). At 30 to 60 DAP, May planting without mulching in open condition (0.096 g g^{-1} day^{-1}) recorded higher RGR which was on par with May planting without mulching in shaded condition (0.094 g g^{-1} day^{-1}). Lower RGR was recorded in August planting without mulching under shade (0.049 g g^{-1} day^{-1}). At 60 DAP to harvest, higher RGR was observed in May planting without mulching under shade (0.039 g g^{-1} day^{-1}) and was on par with June planting under no mulch condition in shade (0.037 g g^{-1} day^{-1}). Lower RGR of 0.025 g g^{-1} $day^{-1}$was recorded in June planting with black polythene sheet under open condition, July planting without mulching and with paddy straw mulching in shaded condition.

4.3.5. Observations on weeds

Interaction between growing condition, planting dates and mulching

Weed density

Combined effect of growing condition, planting dates and mulching on weed density is presented in Table 50. At 30 DAP, highest weed density was recorded from

Table 49. Interaction effect of growing condition, planting dates and mulching crop growth rate, relative growth rate at different growth stages

Treatments	CGR (g $m^{-2}day^{-1}$)				RGR (g $g^{-1}day^{-1}$)			
	30- 60 DAP		60 DAP- harvest		30- 60 DAP		60 DAP- harvest	
	Open	50% Shade	Open	50% Shade	Open	50% Shade	Open	50% Shade
May x No mulch	1.56	0.72	8.17	9.33	0.094	0.051	0.031	0.039
May x Paddy straw	1.70	0.87	9.56	9.33	0.079	0.053	0.031	0.036
May x Black polythene	2.34	2.73	9.33	9.28	0.083	0.077	0.027	0.026
June x No mulch	1.66	1.40	10.91	14.77	0.082	0.068	0.033	0.037
June x Paddy straw	2.01	1.33	6.74	6.73	0.088	0.066	0.026	0.029
June x Black polythene	3.84	2.28	12.00	9.27	0.096	0.072	0.025	0.027
July x No mulch	1.28	1.20	4.56	3.82	0.080	0.063	0.026	0.025
July x Paddy straw	0.48	1.92	4.79	5.82	0.055	0.083	0.036	0.025
July x Black polythene	1.10	1.64	9.64	6.52	0.064	0.063	0.035	0.027
Aug x No mulch	0.59	0.69	5.64	7.56	0.053	0.049	0.035	0.036
Aug x Paddy straw	0.92	1.42	6.94	7.11	0.071	0.068	0.034	0.029
Aug x Black polythene	1.21	1.75	9.21	6.67	0.071	0.065	0.034	0.027
CD (0.05)	0.31		1.18		0.011		0.002	

June planting without mulching in open condition (583.33 no. m^{-2}) and lower weed count recorded in August planting with black polythene mulch (5.33 no. m^{-2}). At 60 DAP, June planted plots with black polythene mulch in open condition recorded higher weed density (414 no. m^{-2}) and lower weed density was noticed in June planting under black polythene mulch in shade (2.67 no. m^{-2}).

Weed dry weight

Interaction between planting dates and mulching had significant influence on weed dry weight at 30 DAP and 60 DAP. From the Table 50. it is clear that in all dates of planting, mulching with black polythene sheet recorded lower weed dry weight. The lowest weed dry weight at 30 DAP was noticed in July planting under open condition and the highest in may planting without mulch in open (149.73 g m^{-2}). At 60 DAP, the same treatment recorded higher weed dry weight of 103.87 g m^{-2}.

Weed control efficiency (WCE)

Weed control efficiency ranged from 20.5 % to 99 % at 30 DAP. Higher weed control efficiency was recorded in July planting with black polythene mulch under open condition (99%). May planting with black polythene mulch in open condition and August planting with black polythene mulch under shaded condition also showed more than 90 per cent weed control efficiency. Lower weed control efficiency was recorded in August planting with paddy straw mulch in open condition (20.51%). At 60 DAP, weed control efficiency ranged from 8.1 % to 98.9 %. More than 90 per cent weed control efficiency was recorded by May and June planting with black polythene mulch under open condition and June planting with black polythene mulch under shaded condition recorded the highest (98.9 %).

Weed Index (%)

Maximum weed index was recorded in July planting in paddy straw mulch under open condition (79.29%) and minimum weed index was recorded in July planting with paddy straw mulch under shaded condition (12.56 %).

4.5 Correlation studies on biometric and quality characters

A correlation matrix between plant characters (Table 51) showed that plant height had significant positive relation with number of branches (0.643), days to first flower (0.676) and andrographolide content (0.409). Number of branches was positively correlated with days to first flower (0.633) and biomass yield (0.695). It was observed that days to first flower has significant positive correlation with the andrographolide content (0.418).

4.4 Cost benefit analysis

The data pertaining to the economics (Rs ha^{-1}) of cultivation of kiriyath under different growing condition, planting dates and mulching are presented in Table 52. Interaction effect between May planting with black polythene mulch under shaded condition recorded higher cost of cultivation of Rs. 626903.20 and the lowest cost of cultivation was observed in July planting with paddy straw mulch in open condition (Rs. 64666.64). A higher B: C ratio of 3.53 was obtained from May planting with black polythene mulching under shaded condition. Planting in July with paddy straw mulch under open condition recorded lower B: C ratio.

Table 50. Interaction effect of growing condition, planting dates and mulching on weed density, weed dry weight, weed control efficiency and weed index at different growth stages.

Treatments	Weed density (no.m^{-2})				Weed dry weight (g m^{-2})				WCE (%)				WI (%)	
	30 DAP		60 DAP		30 DAP		60 DAP		30 DAP		60 DAP			
	Open	50% Shade	Open	50% Shade	Open	50% Shade	Open	50% Shade	Open	50% Shade	Open	50% Shade	Open	50% Shade
May x No mulch	20.79 (432)	19.23 (369)	12.37 (152)	18.15 (330)	12.27 (149.73)	10.07 (100.60)	10.24 (103.87)	7.77 (59.60)	-	-	-	-	28.71	38.59
May x Paddy straw	14.30 (204)	11.79 (138)	8.19 (66)	10.24 (106.67)	9.62 (91.60)	7.86 (60.80)	7.40 (53.80)	6.04 (35.60)	38.58	38.85	48.2	40.0	18.47	19.05
May x Black polythene	4.12 (16)	5.17 (26)	3.37 (10.67)	2.75 (6.67)	3.47 (11.10)	5.57 (30)	3.01 (8.10)	3.06 (8.40)	92.60	70.05	92.2	85.9	-	-
June x No mulch	24.30 (583. 33)	18.08 (326)	20.35 (414)	17.43 (308)	12.00 (143.13)	9.23 (84.20)	9.85 (97.00)	7.34 (52.80)	-	-	-	-	61.47	31.19
June x Paddy straw	15.20 (230)	15.80 (249)	16.87 286)	13.64 (186)	7.58 (56.60)	8.08 (64.40)	8.01 (63.20)	5.56 (29.880	60.44	23.54	32.8	43.4	52.58	31.87
June x Black polythene	7.27 (52)	3.37 (13.3)	3.31 (10)	1.82 (2.67)	5.08 (25)	4.81 (22.40)	2.65 (6.00)	1.22 (0.57)	82.42	73.34	93.5	98.9	-	-
July x No mulch	18.87 (357)	18.08 (326)	8.05 (64)	14.50 (213.33)	10.94 (119.60)	8.34 (68.70)	6.89 (46.50)	6.32 (39.00)	-	-	-	-	70.36	58.04
July x Paddy straw	11.08 (122)	12.19 (148)	11.43 (130)	10.85 (117.33)	8.82 (77.73)	7.28 (52)	6.66 (43.33)	5.91 (34.00)	34.97	23.93	17.1	28.9	79.51	12.56
July x Black polythene	1.00 (0)	3.06 (10.67)	4.43 (18.67)	2.04 (5.33)	1.00 (0)	3.52 (15.87)	3.31 (10.00)	3.05(8.3 3)	99	76.25	81.0	82.6	-	-
Aug x No mulch	14.90 (224)	18.60 (346)	15.42 (238)	15.44 (238)	7.64 (57.40)	8.82 (77)	8.12 (65.00)	10.34 (106.30)	-	-	-	-	69.21	30.53
Aug x Paddy straw	14.57 (214)	13.07 (170)	11.51 (132)	12.37 (152)	6.80 (45.20)	6.82 (45.60)	7.79 (59.73)	6.75 (44.60)	20.51	40.40	8.1	57.4	57.98	13.46
Aug x Black polythene	2.71 (8)	2.04 (5.33)	4.57 (20)	3.39 (13.33)	2.82 (7)	2.03 (5.20)	3.23 (9.48)	4.40 (18.40)	87.93	93.25	85.4	82.6	-	-
CD (0.05)	1.92		2.17		1.33		0.58							

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Table 51. Correlation studies on biometric and quality characters

Characters	Plant height	Number of branches	Days to first flower	Biomass yield	Andrographolide content
Plant height	1	0.643**	0.676**	0.981**	0.409*
Number of branches		1	0.633**	0.695**	0.321
Days to first flower			1	0.331	0.418*
Biomass yield				1	0.158
Andrographolide content					1

Table 52. Interaction effect of growing condition, planting dates and mulching on Benefit: Cost ratio

Treatments	Cost of cultivation (Rs/ha)	Income (Rs/ha)	B:C ratio
$A_1B_1C_1$	130500	325650.00	2.50
$A_1B_1C_2$	164500	399120.00	2.43
$A_1B_1A_3$	177500	442050.00	2.49
$A_1B_2C_1$	130500	194453.36	1.49
$A_1B_2C_2$	164500	226417.80	1.38
$A_1B_2C_3$	177500	480204.40	2.71
$A_1B_3C_1$	130500	96183.28	0.74
$A_1B_3C_2$	164500	64666.64	0.39
$A_1B_3C_3$	177500	312253.28	1.76
$A_1B_4C_1$	130500	164693.32	1.26
$A_1B_4C_2$	164500	225177.80	1.37
$A_1B_4C_3$	177500	389546.68	2.19
$A_2B_1C_1$	130500	402360.00	3.08
$A_2B_1C_2$	164500	504453.20	3.07
$A_2B_1C_3$	177500	626903.20	3.53
$A_2B_2C_1$	130500	394506.68	3.02
$A_2B_2C_2$	164500	391820.00	2.38
$A_2B_2C_3$	177500	573480.00	3.23
$A_2B_3C_1$	130500	171720.04	1.32
$A_2B_3C_2$	164500	352208.96	2.14
$A_2B_3C_3$	177500	409386.80	2.31
$A_2B_4C_1$	130500	271746.72	2.08
$A_2B_4C_2$	164500	321208.88	1.95
$A_2B_4C_3$	177500	538346.80	3.03

- Labour charges (Men – Rs.525/day and Women- Rs. 425/ day)
- Cost of polythene sheet – Rs.7/ m^2
- Sale price of kiriyath – Rs.30/kg

Discussion

5. DISCUSSION

The experiment entitled "Crop weather relation in yield, quality and weed dynamics of kiriyath (*Andrographis paniculata*)" was conducted in the Department of Agronomy, College of Horticulture, Vellanikkara during 2017. The results obtained from the experiment are discussed below based on available literatures.

5.1 Effect of growing condition, plant height and mulching on growth and yield of*Andrographis paniculata*

5.1.1 Plant height

In general, the plant height increased as the crop advanced in age and reaching its maximum at harvest stage. The crops planted under 50 per cent shaded condition recorded the greatest plant height of 7.00 cm, 26.83 cm and 81.36 cm at 30 DAP, 60 DAP and harvest respectively (Table 3, Fig.4 and 5). Increased plant height with the treatment could be attributed to the effect of weather parameters like maximum temperature and solar radiation. Under shaded condition the temperature and solar radiation value were lower compared to open condition (Table 11) and both parameters showed negative correlation with the plant height (Table 12 and 16). Similar result of increase in plant height under 50 per cent shaded condition in *Andrographis paniculata* was reported by Purwanto *et al.* (2011). According to Boardman (1977), plants that grow in shade tend to have elongated growth due to long segment of stem composed of thin walled cells, larger intercellular spaces and fewer transport tissue and binding tissues, which could be caused by the activity of auxin.

The results obtained from the experiment indicated that the plant height measured at 60 DAP and at harvest was significantly affected by different planting dates. Planting on 15th July resulted in taller plants at 60 DAP and at harvest. Lower heights of 10.26 cm and 64.77 cm were recorded in May and June planting respectively at 60 DAP and at harvest (Fig.5 and 6). Significant influence of

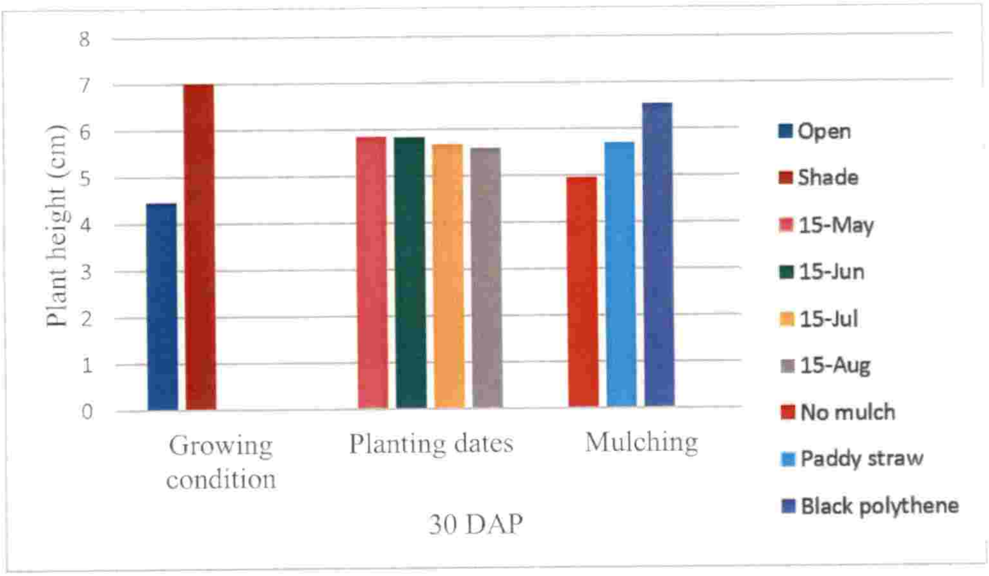

Fig.4 Effect of growing condition, planting dates and mulching on plant height at 30 DAP

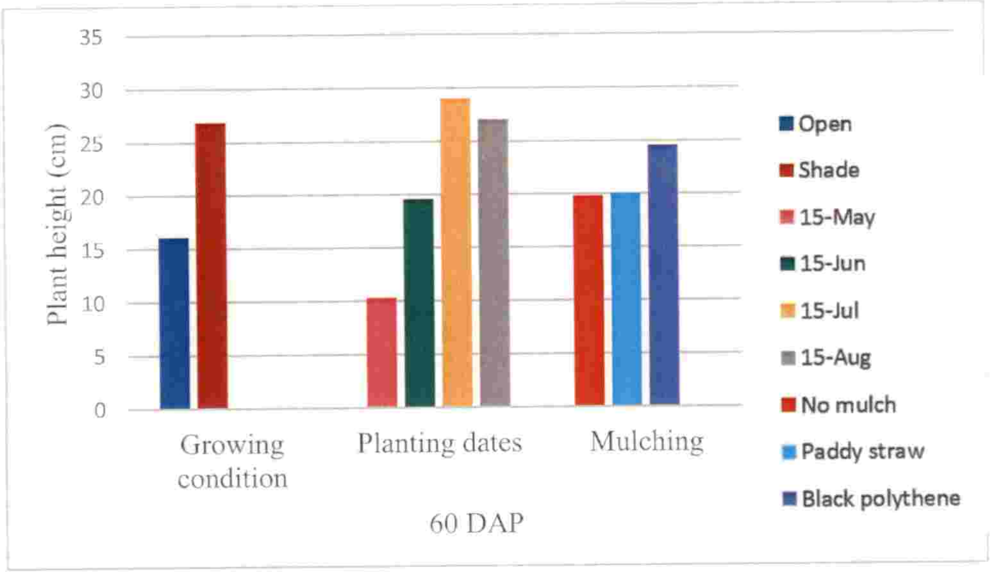

Fig.5 Effect of growing condition, planting dates and mulching on plant height at 60 DAP

seasonal variations on plant height of *Andrographis paniculata* was reported by Tanguturi *et al.* (2017).

As in the case of growing condition and planting dates, mulching also influenced the plant height of *Andrographis paniculata* at different growth stages. Mulching with black polythene recorded the highest plant height throughout the crop period followed by paddy straw mulching (Fig.4, 5 and 6). Increase in soil temperature and soil moisture contents in the plots with mulching compared to bare soil might have contributed to better plant height in these plots (Table 6 and 7). Improvement in height of plants grown under polythene mulches was reported by Kaur (2015) in Solanum.

5.1.2 Number of branches per plant

In general, the number of branches increased from 30 DAS to harvest (Table 3). At 60 DAP, higher number of branches were observed in shaded condition (Fig.7). Higher plant height might have favoured the production of more lateral buds resulting in more number of branches. A strong positive correlation was observed between plant height and number of branches (Table 52). Increase in number of branches per plant with increase in plant height was also reported by Singh and Singh (2006) and Sunil *et al.* (2011) in *Andrographis paniculata*.

Crops planted in June recorded higher number of branches (7.11) at 60 DAP which was on par with August and July planting (Fig.7). At harvest, planting on 15th May recorded the highest number of branches (22.44). Number of branches showed negative correlation with maximum temperature, solar radiation and morning relative humidity and was positively correlated with afternoon relative humidity. A negative correlation with temperature and solar radiation in growth and development of kiriyath was reported by Purwanto *et al.* (2011).

Mulching with polythene sheet and paddy straw exhibited positive effect on number of branches per plant at 60 DAP. During the entire crop period, higher number of branches was observed in black polythene sheet followed by paddy straw mulch (Table 3, Fig.7 and 8). Plots with no mulching always showed lower number of branches. According to Shrivastava *et al.,* (1994), mulched tomato plants produced more branches than unmulched plants. As in the case of plant height, increase in soil temperature and soil moisture contents might have influenced the number of branches too.

5.1.3 Days to first flowering

In general days to first flower coincided with 15th week after planting. Number of days taken for first flowering ranged from 108 to 113. Flowering commenced earlier in the open condition *i.e.* on 109th day whereas it took more days for flowering under shaded condition (116 days). Among different planting dates, 15th July planting took more number of days (118) for flowering, followed by planting in 15th August (115 days). Planting on 15th May and 15th June took lower number of days for flowering (108 and 109 days). Mulching did not show any significant influence on days to first flowering (Table 3, Fig.9). Variation in days to first flowering could be attributed to variation in weather parameters observed under different growing conditions and planting dates. In most crop species, vegetative growth and floral initiation are accelerated by high temperatures. Negative correlation of weather parameters such as temperature and light on flower initiation was reported by Adams *et al.* (1997). In this study, a negative correlation was observed between maximum temperature and solar radiation mainly during flowering to later growth stages (Table 12 and 16).

5.1.4 Biomass yield

Higher biomass yield was noticed under shaded condition (Table 4, Fig.10) indicating that Kiriyath prefers shaded condition. Shade tolerance of *Andrographis paniculata* was reported by many workers such as Omar *et al.* (2016). Significant variation was observed for biomass yield under different dates of planting. The highest biomass yield of 143.93 g plant^{-1} at harvest was obtained in May planting, which was 23.21 per cent more than the next best treatment (June planting) and 47.14 per cent more than lowest treatment (July planting) (Fig.10 and 11). In an

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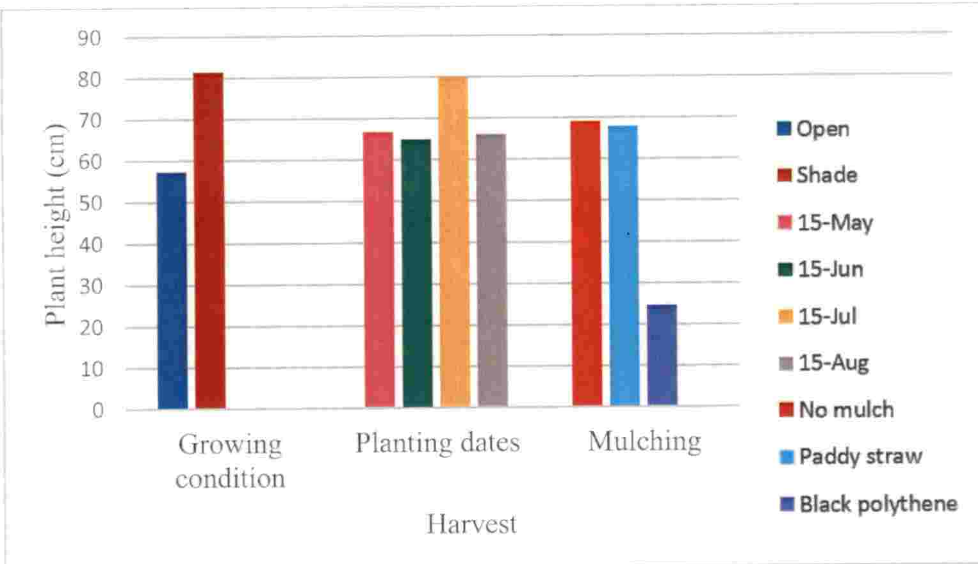

Fig.6 Effect of growing condition, planting dates and mulching on plant height at harvest

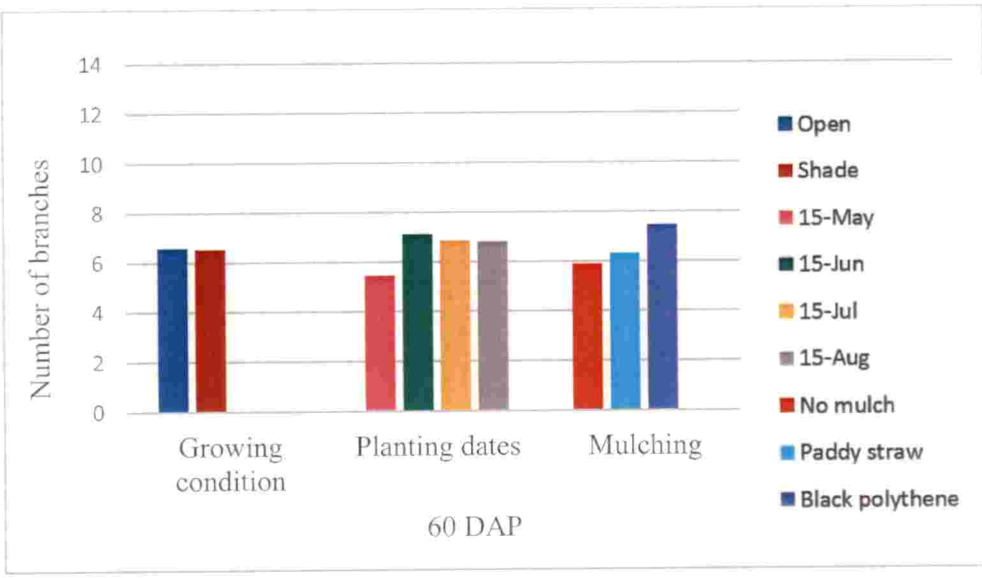

Fig.7 Effect of growing condition, planting dates and mulching on number of branches at 60 DAP

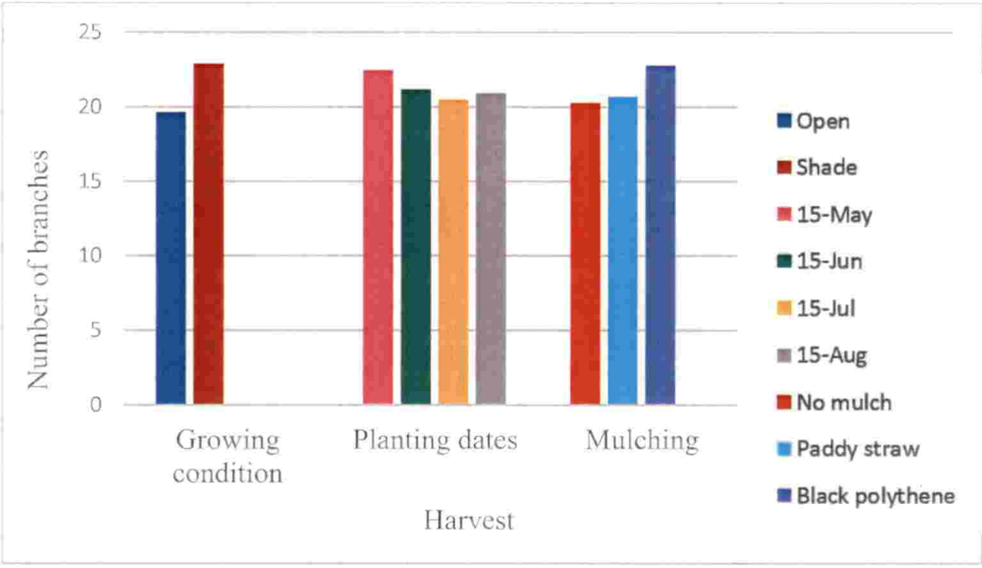

Fig.8 Effect of growing condition, planting dates and mulching on number of branches at harvest

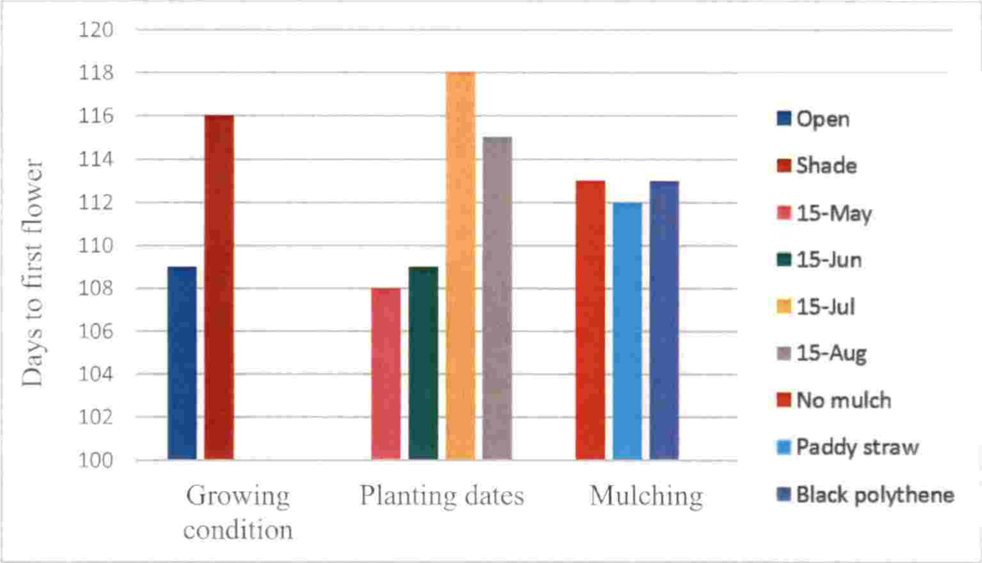

Fig.9 Effect of growing condition, planting dates and mulching on days to first flowering

experiment conducted to evaluate the effect of different planting dates on growth and yield of three *Andrographis paniculata* cultivars Detpiratmongkol *et al.* (2017) concluded that planting dates had significant influence on growth and yield of *Angrographis paniculata* and according to them, the ideal time for planting *Andrographis paniculata* is 1st June under Thailand condition.

Mulching significantly influenced the biomass yield of *Andrographis paniculata* in all growth stages. Black polythene mulching recorded the highest biomass yield of 1.98 g plant^{-1}, 16.70 g plant^{-1} and 137.89 g plant^{-1} at 30 DAP, 60 DAP, and at harvest respectively (Table 4, Fig. 10, 11, 12). Significant influence of mulching on increasing fresh herb weight of *Andrographis paniculata* was reported by Panwar *et al.* (2017). Improved soil moisture content, optimum soil temperature and reduced weed infestation (Tables 6, 7 and 10) might have contributed to the increased biomass yield under mulched plots. The possible reason for increase in fresh weight in crop planted on 15th May under shade and mulched with black polythene may be increase in plant height and number of branches resulting from congenial weather parameters. A strong positive correlation could be observed between plant height, number of branches and biomass yield (Table 52).

5.1.5 Total yield

Total yield of crop followed the same trend as that of biomass yield at harvest. Growing condition, planting dates and mulching significantly influenced the total yield of *Andrographis paniculata*. The highest yield of 10,019 kg ha^{-1} was noticed in the crop grown under 50 per cent shaded condition. The yield under open condition was 1981 kg less than shaded condition (Table 4 and Fig.13). According to Purwanto *et al.* (2011), *Andrographis paniculata* prefers 25 to 50 per cent shade for better growth and development. Among different dates of planting, May planting recorded the highest total yield of 12873 kg ha^{-1} which was 54.14 per cent more than the lowest yielding treatment (July planting). Reduction in chlorophyll content due to unfavourable weather parameters observed during the period (Table 8) may be the reason for reduction in total yield in the crop planted during July.

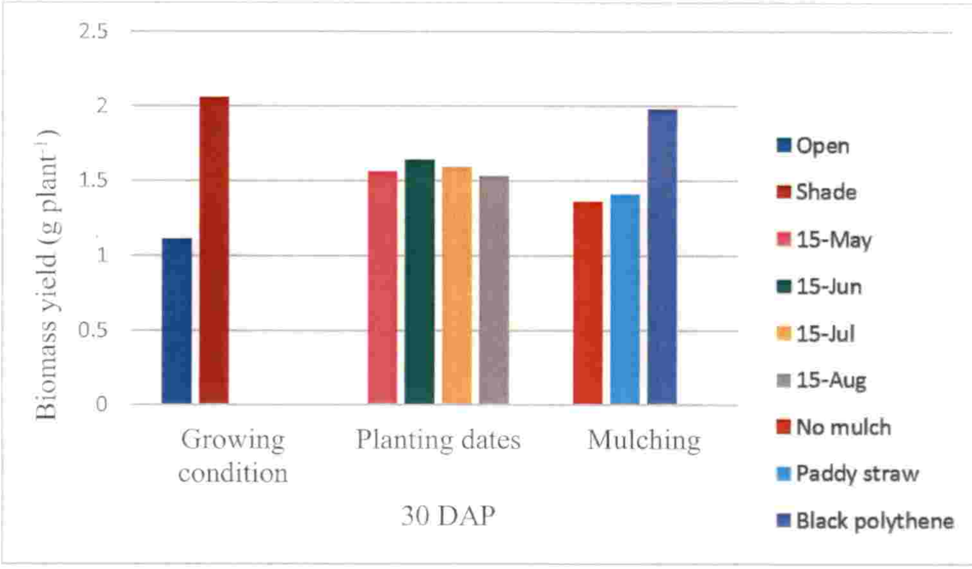

Fig.10 Effect of growing condition, planting dates and mulching on biomass yield at 30 DAP

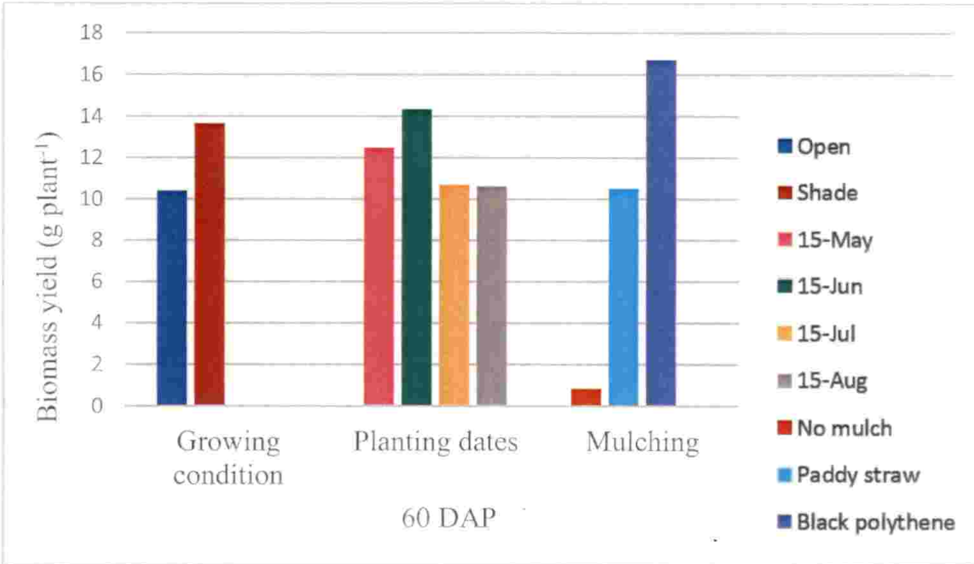

Fig.11 Effect of growing condition, planting dates and mulching on biomass yield at 60 DAP

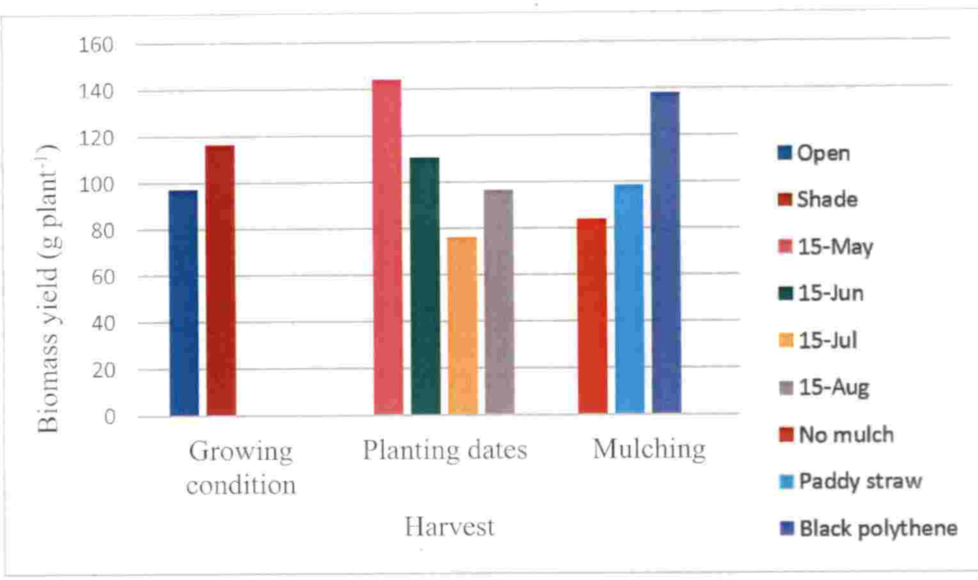

Fig.12 Effect of growing condition, planting dates and mulching on biomass yield at harvest

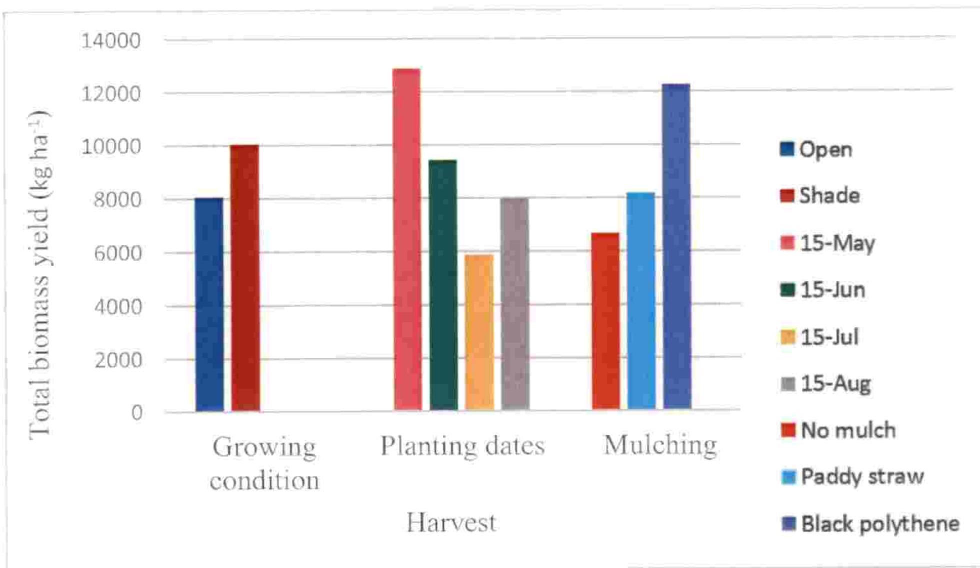

Fig.13 Effect of growing condition, planting dates and mulching on total biomass yield at harvest

Since chlorophyll is the basic material for plant photosynthesis and its levels determine the photosynthetic rate, reduction in chlorophyll will lead to reduction in crop yields (Zhang *et al.*, 2013). Black polythene mulching continued its superiority with respect to total yield also. There was 45.66 per cent difference in yield between treatments with black polythene mulch and unmulched plots (Fig.13).

5.2 Effect of growing condition, plant height and mulching on soil chemical properties

Soil pH, organic carbon, available N, P, and K were analyzed before and after experimentation. In general soil pH, organic carbon and available N content increased after the experiment and K contents decreased. The available content of P remained almost uniform. After the experiment, available K content of soil alone was significantly influenced by different treatments. It was higher in open condition compared to that of shade. This might be due to the presence of unutilized K in the soil due to reduced plant growth. Available K content in the soil was lower after the experiment in May planted plots. This might be due to the increased uptake and resultant high total yield. It was found that available K content was higher in paddy straw mulched plots (Fig.14). According to Khan *et al.* (2002) application of straw mulching increased available N, P and K status in soil. Compared to unmulched soil, the content of K was more in plots with mulching. Improved nutrient availability under mulched plots than unmulched plots was reported by Agele *et al.* (2000).

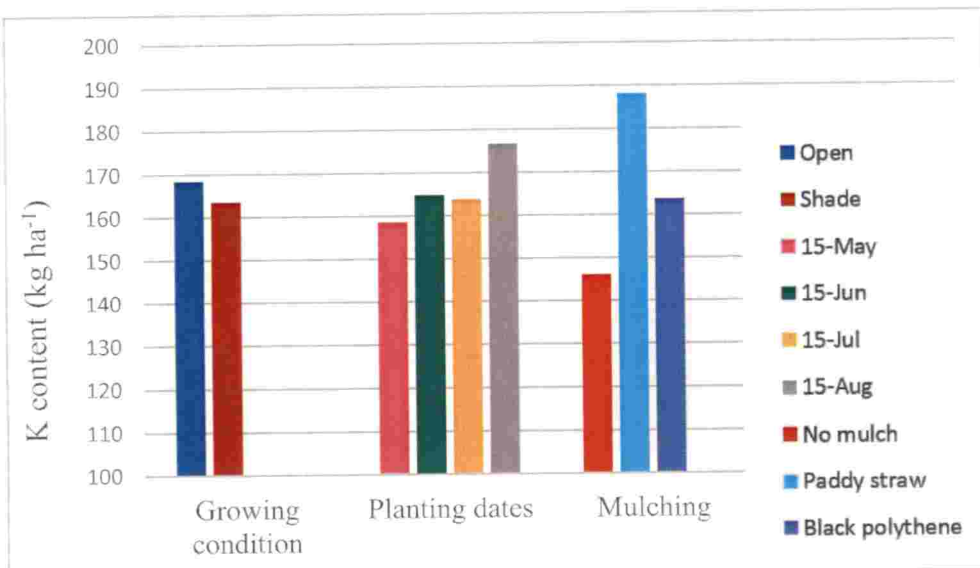

Fig.14 Effect of growing condition, planting dates and mulching on available K content in soil

5.3 Effect of growing condition, plant height and mulching on micrometeorological observations

5.3.1 Soil temperature

Lower soil temperature was observed in shaded condition throughout the growing period (Fig.15). Dodd *et al.* (2005) observed lower soil temperatures under shaded conditions, compared to open pasture. Throughout the crop growth period, the soil temperature remained unaffected by planting dates. However, mulching exhibited significant variation with respect to planting dates. The polythene mulched soil consistently recorded higher temperature (Fig.16). According to Hu *et al.* (1995) a rise in soil temperature under polythene sheet may be due to solar energy trapped inside the mulch material through green house effect. On an average there was 2^0C increase in soil temperature under polythene mulch. Ghosh *et al.* (2006) reported that in groundnut, black polythene mulch increased soil temperature by 4-5°C during the crop period.

5.3.2 Soil moisture

The soil moisture content at 15 cm depth ranged from 57.90 per cent to 12.66 per cent during the entire crop period. Comparing open and shaded growing condition, soil moisture content at 15 cm depth was higher under shade throughout the study (Table 7, Fig.17). Dodd *et al.* (2005) also reported higher soil moisture content under shade than open condition. Soil moisture content was significantly influenced by different planting dates. Saturated soil moisture status was observed at 42 DAP of May planting, 60 DAP of July planting and 42 DAP of August planting (Fig.18). This can be correlated with monsoon rains received during this period (Appendix 1).

Mulching significantly influenced the soil moisture content at 15 cm depth at different growth stages of the crop. Compared to no mulching, the treatments with mulching recorded higher moisture content. As per Sharma and Kathiravan (2009) mulched plots retain higher soil moisture than unmulched plots.

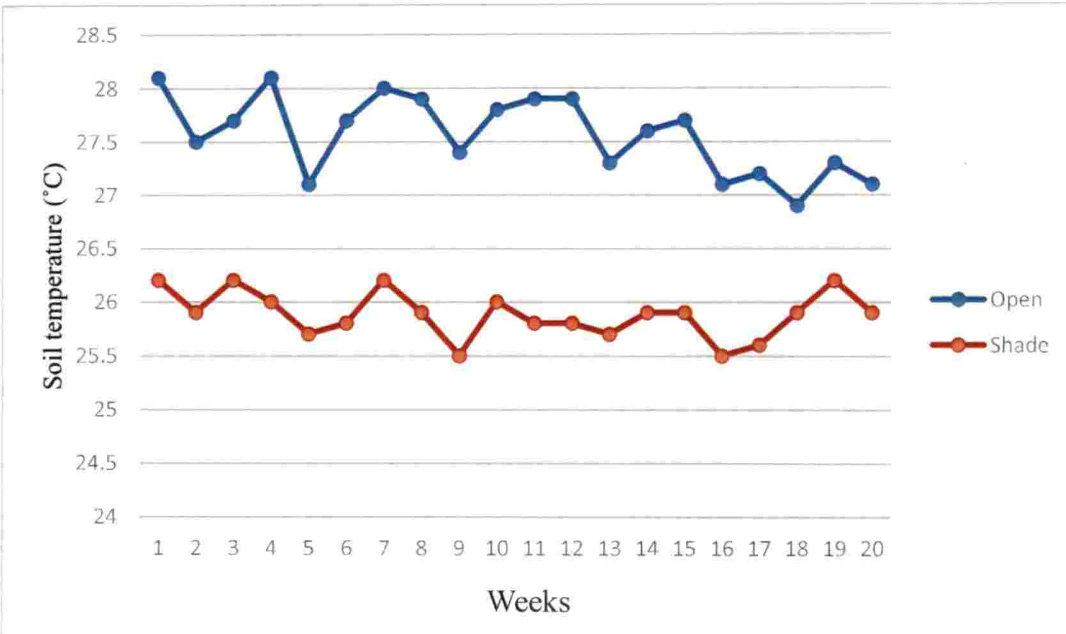

Fig.15 Effect of growing condition on soil temperature

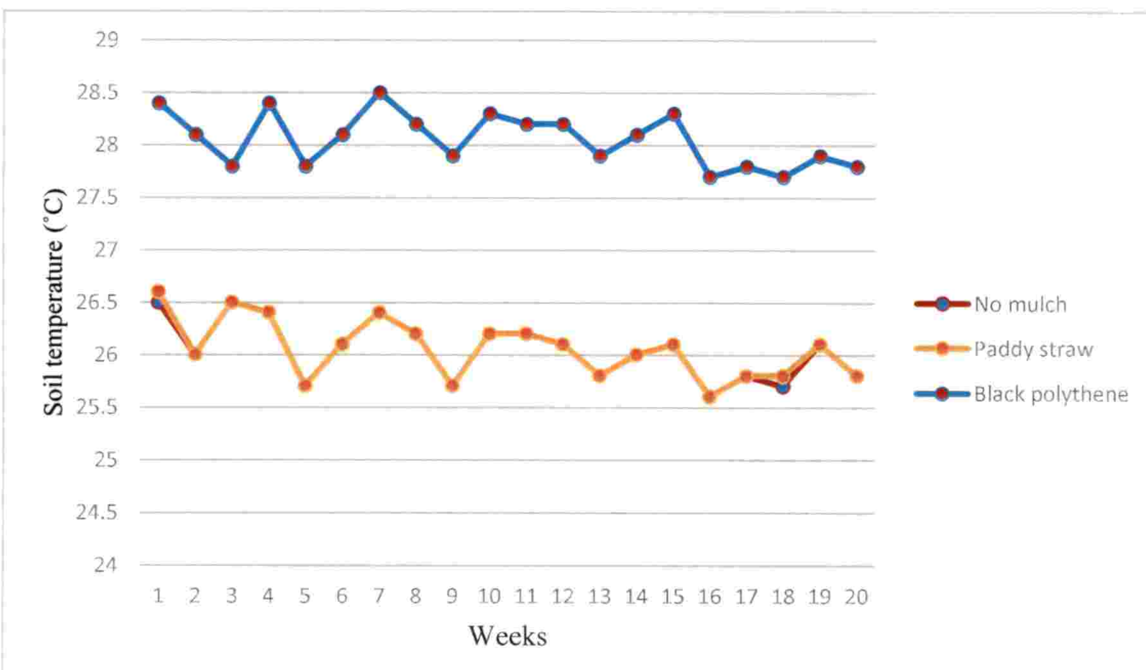

Fig.16 Effect of mulching on soil temperature

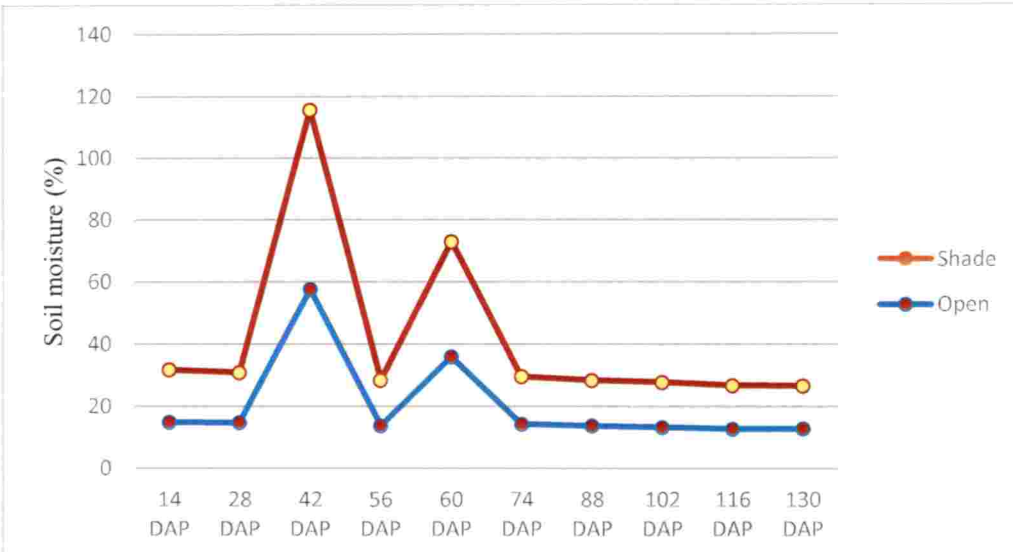

Fig.17 Effect of growing condition on soil moisture

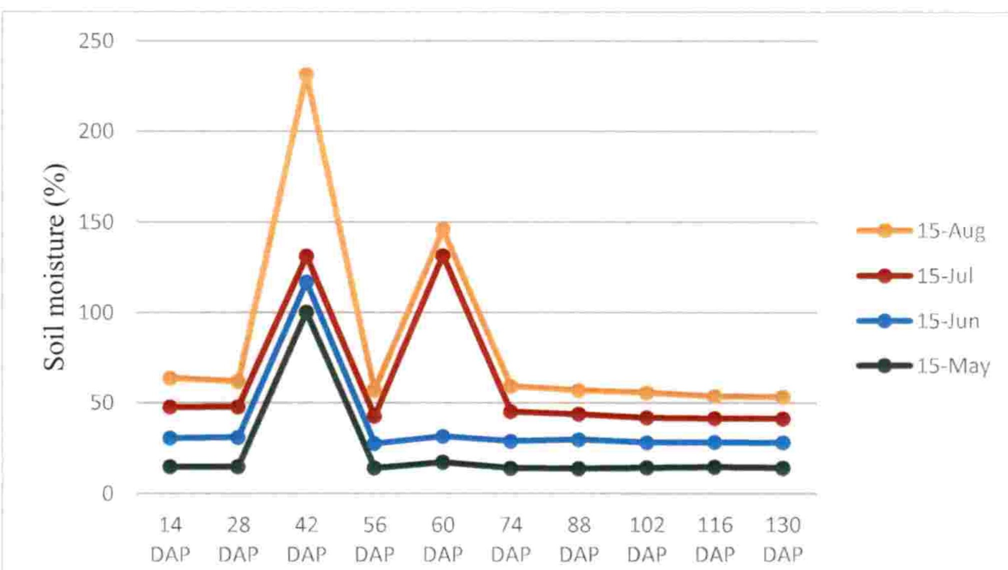

Fig.18 Effect of planting dates on soil moisture

Significantly higher moisture content was observed under black polythene mulch (Fig.19). According to Lalitha *et al.* (2010), higher moisture content under polythene mulch was due to reduced evaporation rate. According to Liakatas *et al.* (1986) plastic mulches directly affect the microclimate around the plant by modifying the radiation budget of the surface and decreasing the soil water loss.

5.4 Effect of growing condition, plant height and mulching on physiological, chemical and biochemical observations

5.4.1 Total chlorophyll

Results of biochemical analysis revealed that total chlorophyll content was higher under shaded condition in all the growth stages (Table 8, Fig.20). Palaniswami (2005) observed that plants grown under partial shade had 53 per cent higher chlorophyll concentration than the plants grown under open condition. According to him, this could be due to high light intensity which often decreases chlorophyll content in plants by inhibiting chloroplast formation. Similar results of increased chlorophyll content under shade was also reported by Kapur (1999) and Naidu and Swamy (1993). Under shaded condition, an increase in chlorophyll content in leaves helps in trapping the available incident light effectively (Johnston and Oneuweme, 1998). Planting dates also influenced the chlorophyll content of *Andrographis paniculata.* At 30 DAP and at harvest, highest chlorophyll content were recorded in 15^{th} May planting (Fig. 21 and 22) which also recorded highest total yield of 12.87 t ha^{-1}. Influence of planting dates on total chlorophyll content was reported by Abou-Dahab *et al.* (2014). During all growth stages, lower content of total chlorophyll was recorded from crop planted in July. Reduction in chlorophyll may be correlated with very low solar radiation received during the initial stages of crop planted in July (Table 11).

Mulching influenced chlorophyll content in all the growth stages. At harvest higher chlorophyll content was exhibited by paddy straw mulching followed by black polythene mulch (Fig.20, 21, 22). Zhang *et al.,* (2015) and Sekhon *et al.,* (2005), observed high chlorophyll content in plants with mulching. As per Zhang

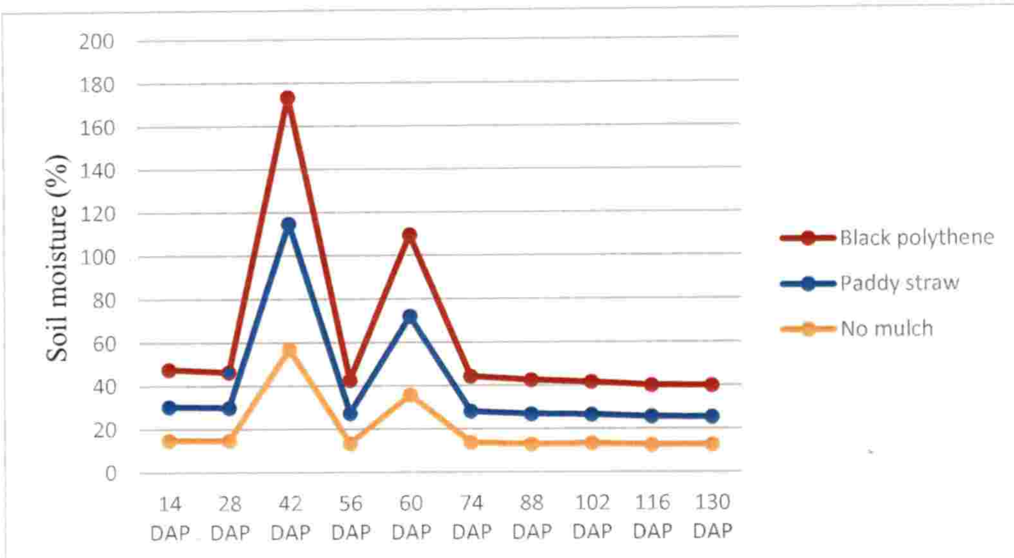

Fig.19 Effect of mulching on soil moisture

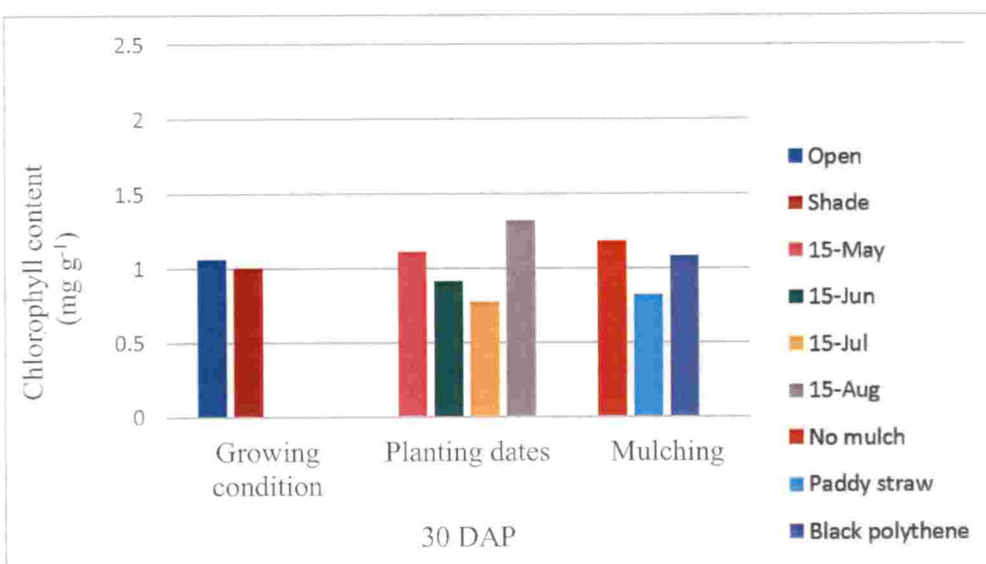

Fig.20 Effect of growing condition, planting dates and mulching on total chlorophyll content at 30 DAP

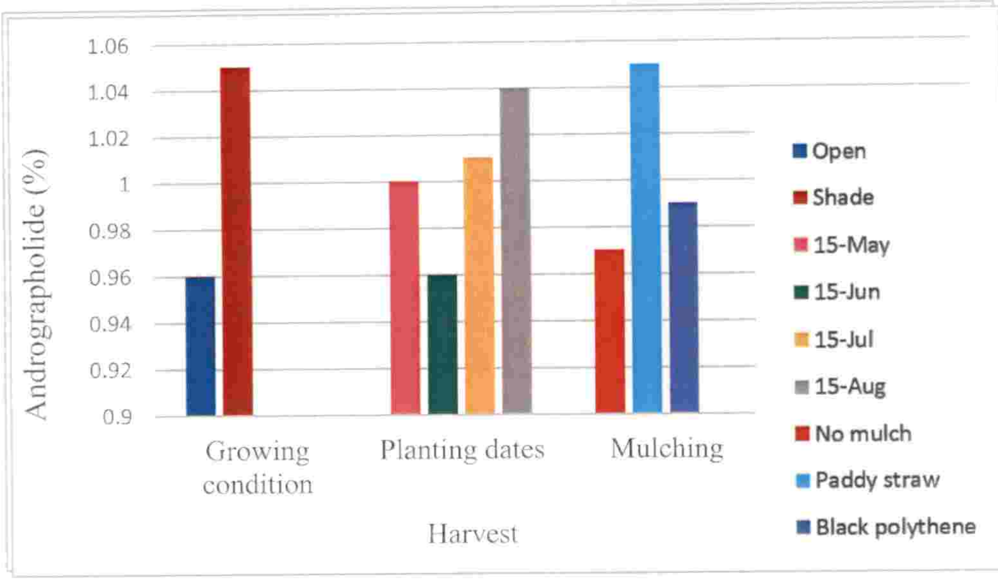

Fig.21 Effect of growing condition, planting dates and mulching on total chlorophyll content at 60 DAP

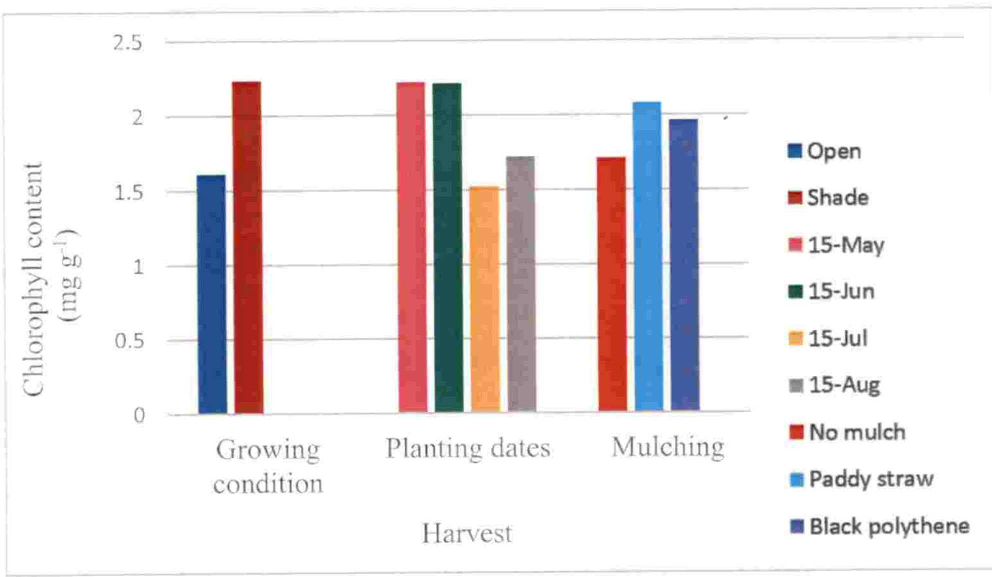

Fig.22 Effect of growing condition, planting dates and mulching on total chlorophyll content at harvest

et al. (2015) straw mulching improved soil microbial activities, enzyme activities and improved plant chlorophyll content and thereby photosynthetic ability of crops. Higher biomass yield in polythene mulched plots can be related to high chlorophyll contents at all stages of observation (Table 8).

5.4.2 Andrographolide content

Secondary metabolites are important biochemical compounds synthesized by medicinal plants and as far as *Andrographis paniculata* is concerned andrographolide is the most important secondary metabolite present in it. HPLC analysis result of andrographolide content as affected by the growing conditions revealed that 50 per cent shaded condition recorded higher andrographolide concentration (1.05%) than open condition (0.96%) (Fig.23). Similar result of higher andrographolide content in Andrographis under 50 per cent shaded condition was reported by Purwanto *et al.* (2011). Planting dates also showed significant influence on andrographolide content. Crops planted in August showed highest andrographolide content. Tanguturi (2013) also observed higher andrographolide content in Androgaphis when the crop was planted on 1st week of August. Environmental factors *viz.* temperature, humidity, light intensity, the supply of water, influences the growth of a plant and secondary metabolite production. From the correlation data (Table 12) it was found that andrographolide content was negatively correlated with maximum temperature during the flowering and harvesting stages. Andrographolide content was significantly more in paddy straw mulched plots (1.05 %) and has found minimum in no mulch condition (Table 8, Fig.23). In an experiment conducted to evaluate effect of planting dates and mulching on yield and quality of strawberry under polyhouse condition, Das *et al.* (2013) observed variations in physico - chemical properties of fruits by modifying dates of planting and providing mulches.

5.4.3 Crop growth rate and Relative growth rate

Growing condition did not exhibit significant influence on crop growth rate. However, during early stages, relative growth rate was significantly influenced by growing condition with greater RGR under open condition (Fig.26) Planting dates had influenced crop growth rate and relative growth rate at different growth stages (Table 9). Both CGR and RGR were found higher in June planting. Favourable weather parameters observed during the crop period might have contributed to better values in this treatment. Mulching with black polythene sheet recorded higher CGR and RGR at initial stages (Fig.24, 25, 26 and 27). This may be due to the effective weed control (Table 10), which significantly increased CGR. Similar results of increased CGR in weed free treatment was also reported by Meena *et al.* (2017).

5.5 Effect of growing condition, plant height and mulching on weed growth

Growing condition significantly influenced the weed count at 30 DAP and weed dry weights at 30 and 60 DAP. Compared to open condition, lower weed density and dry weights were observed under shaded condition (Fig.28, 30 and 31). This could be due to increased plant growth under shaded condition which reduced light interception. In general, June planted plots recorded higher weed density at 30 and 60 DAP. This may be due to the high rainfall during the period. However, weed dry weight was higher in May and June planted crops at 30 DAP and in August planted crop at 60 DAP (Fig. 30 and 31). Very few weeds were noticed in plots with black polythene which germinated through holes made for planting. At 30 DAP and 60 DAP, lower weed density and dry weight was observed in black polythene sheet mulch (Table 10). Superiority of black polythene sheet in controlling weed growth in medicinal coleus was reported by Gunasekaran and Shakila (2014). According to them, weed suppression by mulching is by increasing the soil temperature and killing the weed seeds in the early stages and also by acting as a physical barrier between sunlight and soil. The next better treatment considering lower weed density and dry weight was paddy straw mulching. Significant reduction in weed density and dry weight by the application of straw mulch was reported by Ramakrishna *et al.* (2006).

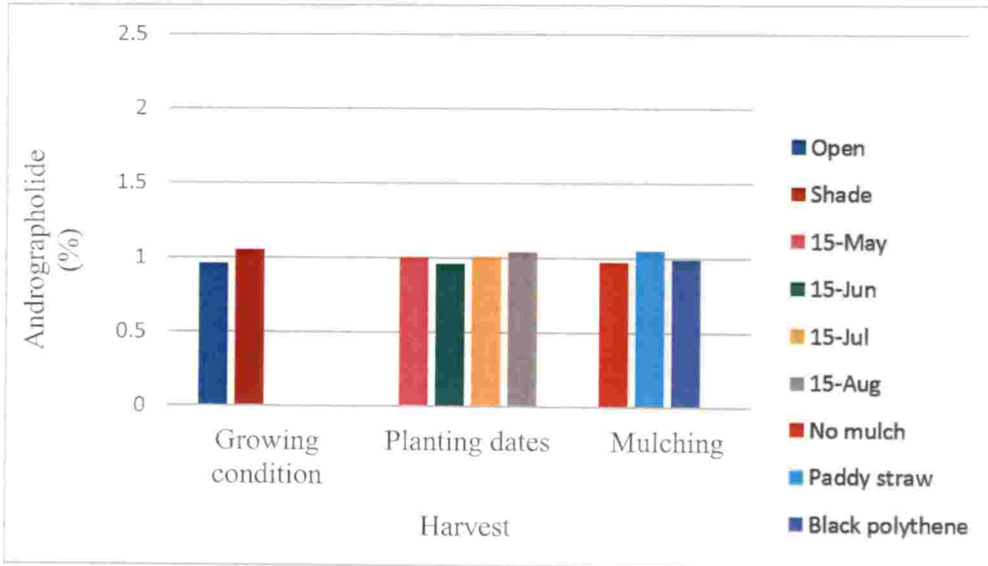

Fig.23 Effect of growing condition, planting dates and mulching on andrographolide content

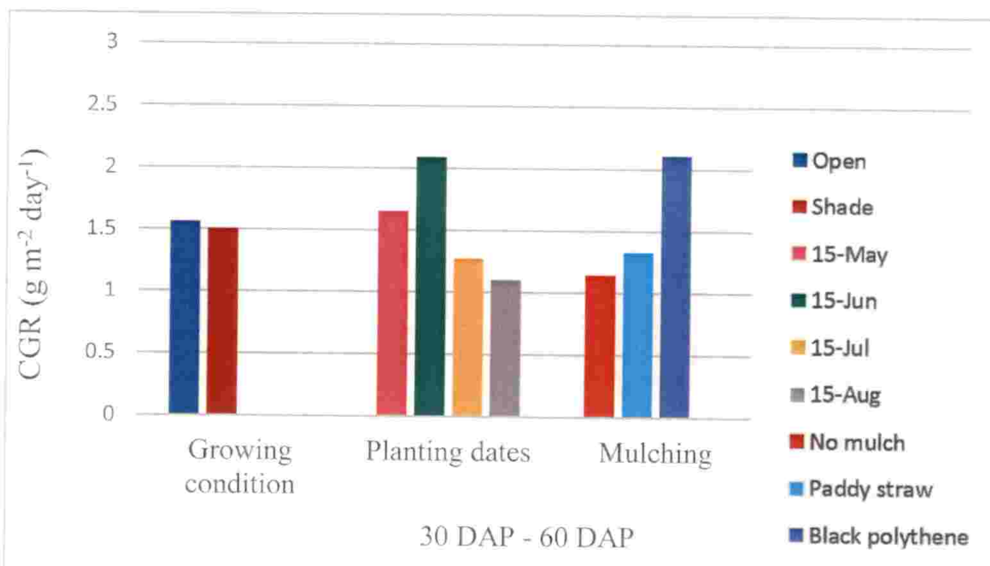

Fig.24 Effect of growing condition, planting dates and mulching on crop growth rate at 30 - 60 DAP

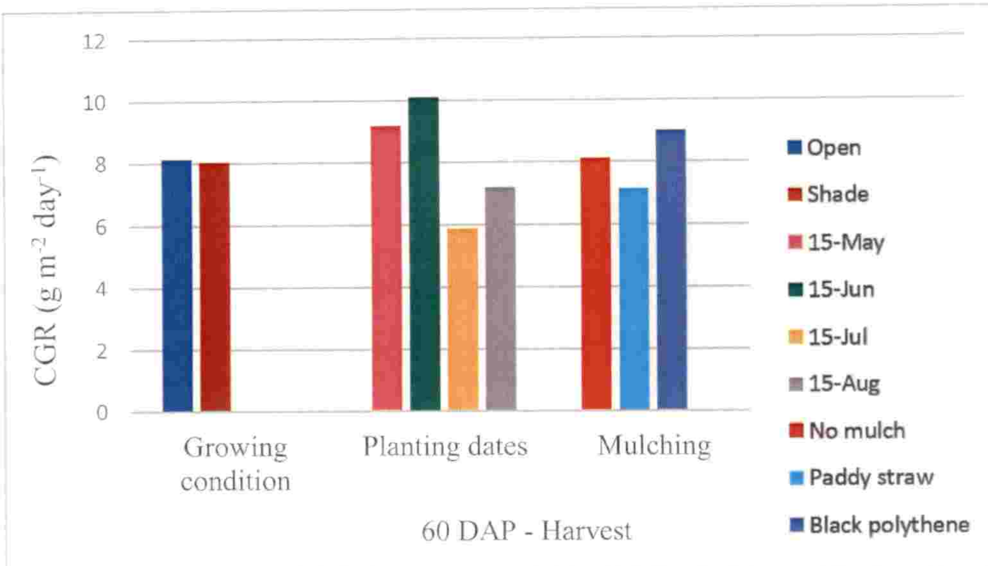

Fig.25 Effect of growing condition, planting dates and mulching on crop growth rate at 60 DAP –Harvest

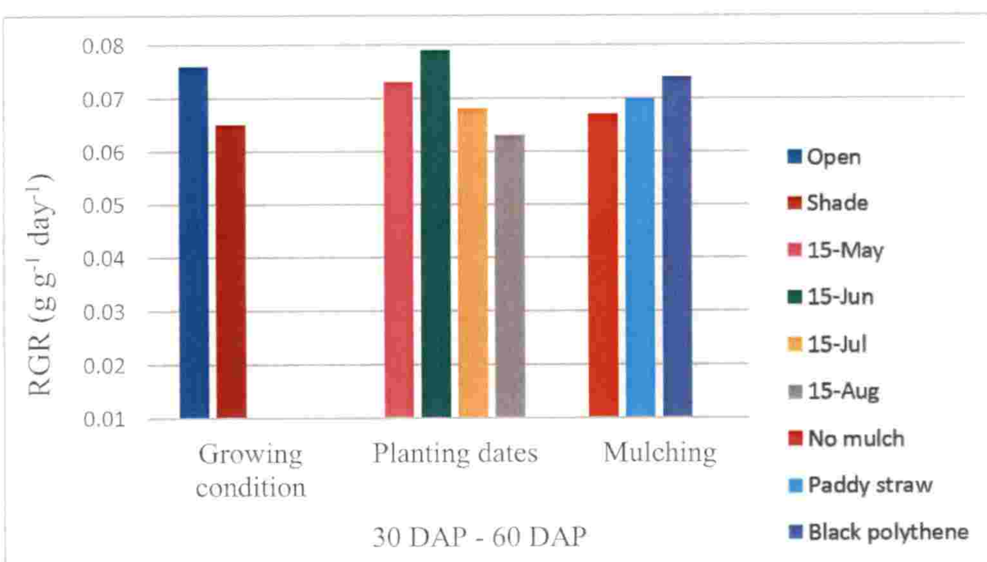

Fig.26 Effect of growing condition, planting dates and mulching on relative growth rate at 30 - 60 DAP

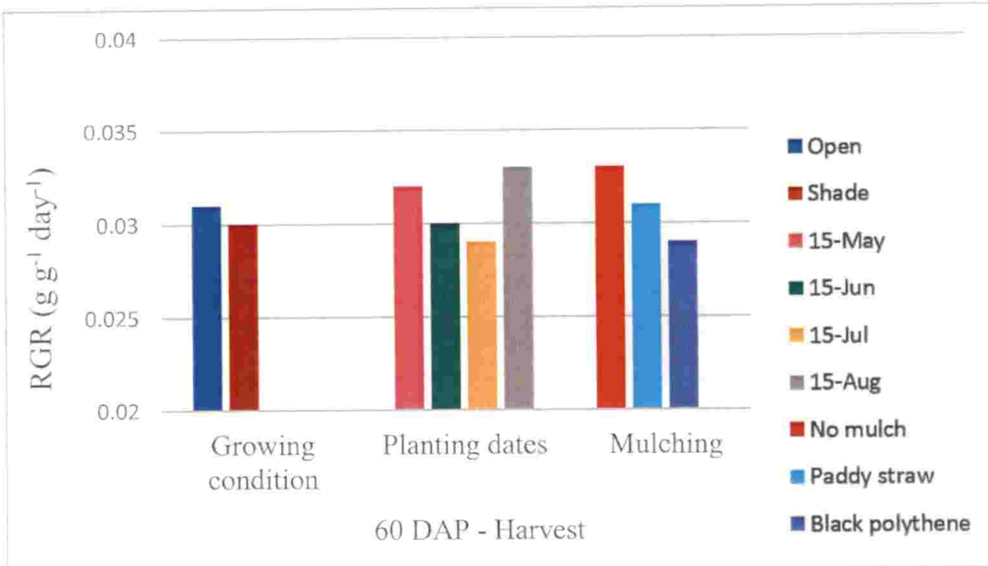

Fig.27 Effect of growing condition, planting dates and mulching on relative growth rate at 60 DAP - Harvest

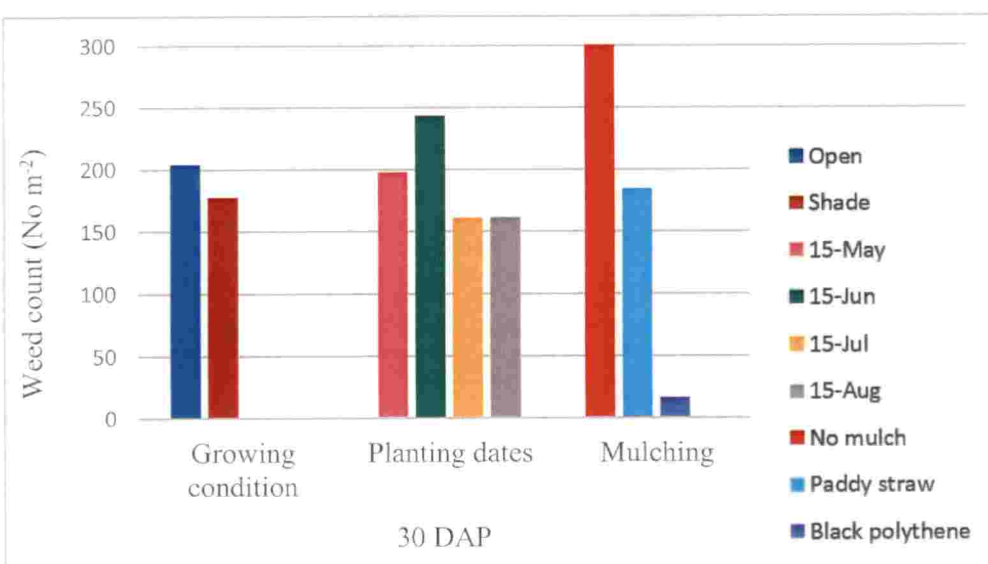

Fig.28 Effect of growing condition, planting dates and mulching on weed density at 30 DAP

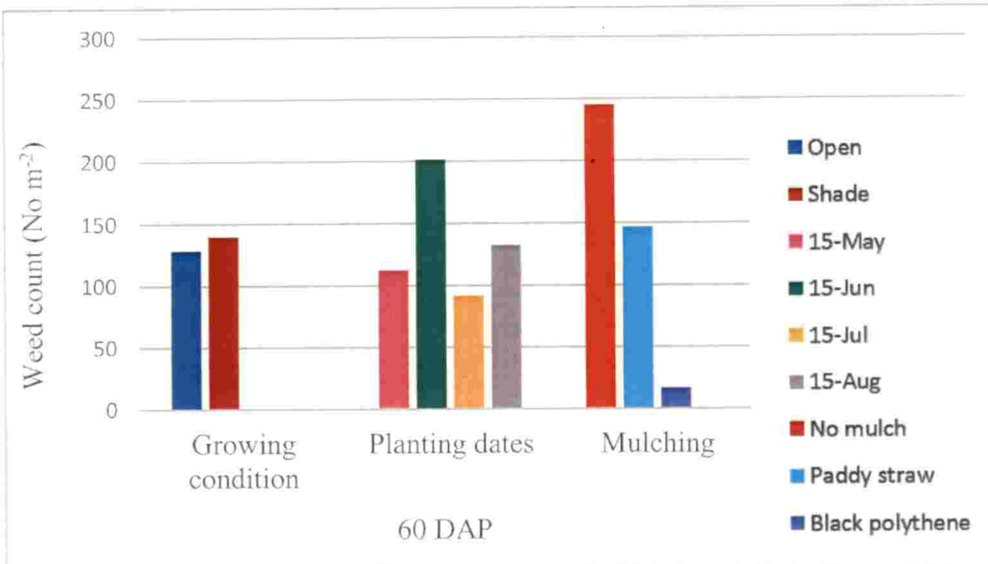

Fig.29 Effect of growing condition, planting dates and mulching on weed density at 60 DAP

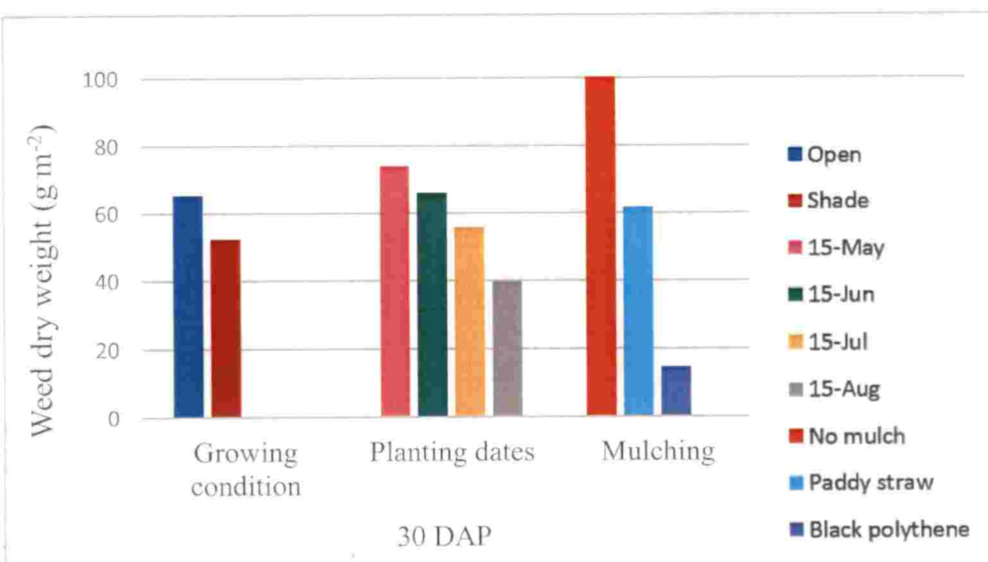

Fig.30 Effect of growing condition, planting dates and mulching on weed dry weight at 30 DAP

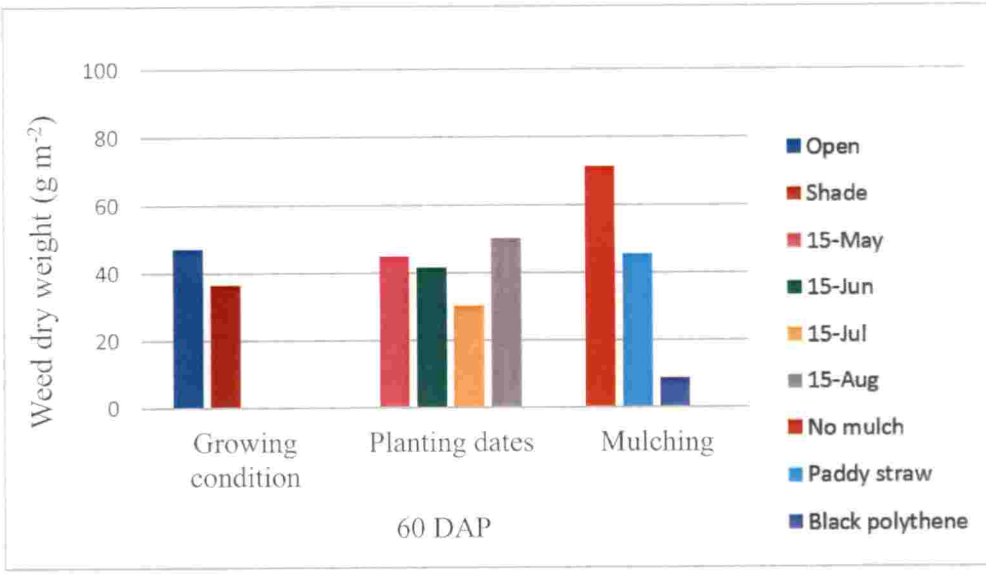

Fig.31 Effect of growing condition, planting dates and mulching on weed dry weight at 60 DAP

Use of polythene mulch proved to be the best practice in controlling weeds throughout growing period compared with the other treatments. Among the mulching treatments higher weed control efficiency was under the treatment combinations with black polythene mulch. Velmurugan *et al.* (2017) reported 100 per cent weed control efficiency in cassava under black polythene mulched treatment. Giri *et al.* (2016) reported similar result of lowest weed index in weed free treatment in sweet basil.

5.6 Crop weather correlations observed during the study

Simple linear correlation between important morphological, yield and quality characters and mean weekly weather parameters like surface air temperature, relative humidity (forenoon and afternoon), wind speed, solar radiation and rainfall indicated that maximum temperature had negative correlation with plant height, number of branches, days to first flowering, biomass yield at later growth stages and andrographolide content. A negative correlation with temperature and solar radiation in growth and development of Kiriyath was reported by Purwanto *et al.* (2011). As per Haridasan (2016), increase in maximum temperature coupled with high soil temperature resulted in an increase in number of days for flowering. Minimum temperature exhibited positive correlation with plant height at flowering stage, number of branches, biomass yields. Sattar *et al.* (2014) reported positive correlation of minimum temperature with yield of sugarcane. The correlation with minimum temperature and andrographolide content was negative during most of the periods. Rainfall had negative correlation with biomass yield initially later on it influenced biomass positively. Forenoon and afternoon relative humidity had negative correlation with plant height, number of branches, days to first flowering and andrographolide content. Solar radiation had negative correlation with plant height, number of branches, days to first flowering, biomass yield and andrographolide content. Purwanto *et al.* (2011) also reported negative correlation with temperature and solar radiation in growth and development of kiriyath.

Interaction effect of growing condition, planting dates and mulching

The interaction between growing condition, planting dates and mulching was found significant with respect to biomass yield and andrographolide content.

At 60 DAP, maximum biomass per plant was recorded in treatment combination, May planting with black polythene sheet under 50 per cent shade and was on par with June and August planting with black polythene sheet under shaded condition (Table 45). At harvest, maximum biomass was recorded in May planting with black polythene sheet under 50 per cent shade. Same trend followed with respect to total biomass per hectare too. Under best treatment combination of planting and mulching (May X Black polythene) by altering only the shade level, yield increase of around 1000 kg could be observed, indicating shade loving nature of *Andrographis paniculata*. Optimum micro and macro meteorological parameters, growing condition and reduced weed infestation in this combination might have contributed to higher biomass yield.

Maximum andrographolide content was found in the crop planted in July with paddy straw mulch under shaded condition and was on par with August planting with paddy straw mulch under 50 per cent shade. According to Bohnert *et al.* (1995), stress conditions had great impact on the metabolic pathways responsible for the accumulation of secondary plant products. Lower biomass yield recorded with the combination involving August and July planting might be due to stress condition which in turn increased the andrographolide content. Stress related increase in monoterpene concentration in sage (*Salvia officinalis*) and loss in biomass was reported by Nowak *et al.,* 2010.

Economic suitability

B: C ratio was the highest for May planting with black polythene mulch. Highest B: C ratio was obtained for May planting with black polythene mulching under shaded condition (Table 53 and Fig.32). Higher B: C ratio under shaded condition and mulching with black polythene can be attributed to the higher yield obtained in that condition, and this highlights the suitability of growing kiriyath under shade and mulch. Lower B: C ratio obtained in July planting could be due to lower yield with that treatment because of the unfavourable weather condition.

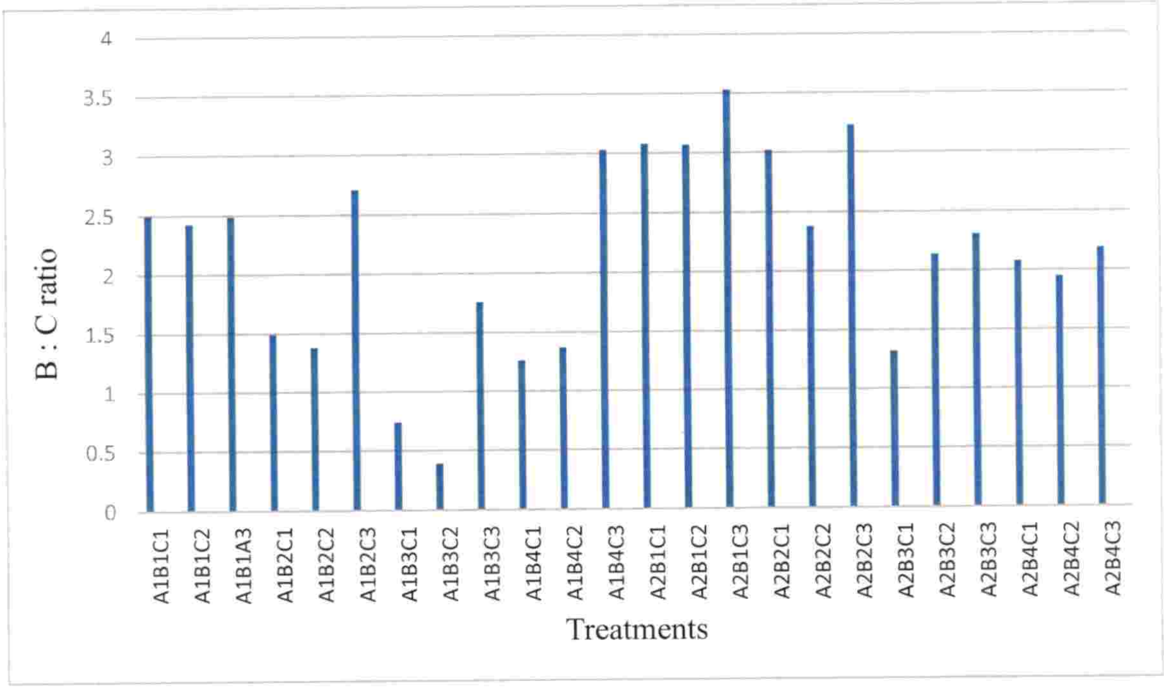

Fig.32 Effect of treatments on B: C ratio

Summary

6. SUMMARY

The present work entitled "Crop - weather relations on yield, quality and weed dynamics of Kiriyath (*Andrographis paniculata* (Burm.f.) Wall. ex. Nees.) was carried out to assess the effect of variations in growing conditions, time of planting and mulching on yield, quality and weed dynamics of *Andrographis paniculata.* The experiment was conducted at the Agronomy farm, Department of agronomy, College of Horticulture, Vellanikkara, Thrissur. The trial was laid out in Randomized Block Design (factorial) replicated thrice. The treatment consisted of two growing conditions viz., open and 50 per cent shade, four dates of planting viz., 15th May, 15th June, 15th July and 15th August and three mulching viz., no mulching, paddy straw mulching and black polythene mulching. Observations were taken on biometric characters, macro and micro meteorological parameters, soil characters, physiological, chemical and biochemical analysis of plants and observations on weeds. Economics cultivation was also worked out. The salient features of the research are summarized and listed here under.

Effect of growing condition

Growing condition had significant influence on performance of crop. Shaded condition greatly influenced the plant height at 30, 60, and harvest. It also influenced the number of branches at 60 DAS. Days to first flowering also showed significant variation due to differences in growing conditions. Flowering occurred earlier under open condition while it took more days to flower under shade. Fresh biomass yield was higher under shaded condition. Growing condition favoured available K content in soil and it was higher in open condition. Considerable effect of growing condition on soil micrometeorological observations like soil temperature and soil moisture was noticed. Soil temperature was higher in open condition where as higher moisture was observed in shaded condition. At 60 DAP and harvest, plants under shade showed higher total chlorophyll content. Andrographolide content also followed similar trend with higher content under shaded condition. Relative growth rate between 30 to 60 DAP was higher under open condition.

Effect of planting dates

Plant height was significantly influenced by different planting dates at 60 DAP and harvest. Crop planted in July recorded maximum plant height. Maximum number of branches was observed in June planted crops and was on par with August and July planting (60 DAP). At harvest, crops planted in May recorded higher number of branches. Minimum number of days taken for flowering was by the crops planted in May and June. Highest biomass yield was found with June planted crops (at 60 DAP) and May planted crops (at harvest). Significantly higher yield was recorded by crop planted in May. Available K content in soil after the experiment was higher in August planted plots. Soil temperature was not influenced by planting dates. However, there was significant variation in soil moisture contents. Physiological, chemical and biochemical parameters also significantly influenced by planting dates. Higher chlorophyll content was noticed in August planting (at 30 DAP), June planting (at 60 DAP) and May planting (at harvest). Andrographolide content was significantly higher in August planting. Crop planted in June recorded significantly higher CGR at different growth stages. RGR was significantly higher in June planting at 30 to 60 DAP and had no effect at 60 DAP to harvest. The crop planted in July recorded lowest weed count and lower weed dry weight was observed in August planting (at 30 DAP) and July planting (at 60 DAP).

Effect of mulching

Mulching had significant effect on plant height at 30 DAP, 60 DAP and harvest. Black polythene mulching greatly influenced plant height, number of branches, fresh biomass yield and total yield. Available K content was higher in paddy straw mulched plots. Mulching with black polythene exhibited higher soil temperature throughout crop growth. Soil moisture content was also showed same trend of soil temperature. At harvest, higher total chlorophyll content was recorded from plants under paddy straw mulch. Andrographolide content was significantly higher in paddy straw mulching. Higher CGR was found under black polythene at different growth periods and RGR was found higher in no mulch condition. Black polythene mulching was the best treatment when weed control is considered followed by paddy straw mulching.

Effect of Interaction between growing condition, planting dates and mulching

At harvest, interaction between growing condition, planting dates and mulching had significant influence on fresh biomass yield and total yield. The crop planted in shaded condition on 15th May under black polythene mulch recorded highest fresh biomass yield and total yield. Available K content in the soil after experiment was significantly higher in August planting with paddy straw mulch under shaded condition. Total chlorophyll content was found significantly higher in June planting with paddy straw mulch under shade and andrographolide content was higher in July planted crops with paddy straw mulching under shade and was on par with August planting with paddy straw mulching under shade. CGR and RGR were also influenced significantly by the combined effect of growing condition, planting dates and mulching. Higher CGR at 30 to 60 DAP was observed in May planting in black polythene sheet under shade and at 60 DAP to harvest in June planting without mulching under shade. Higher RGR was recorded in May planting without any mulch in open condition (30 to 60 DAP) and May planting without any mulch under shade (60 DAP to harvest) and was on par with June planting under no mulch in shade. Interaction between growing condition, planting dates and mulching significantly influenced weed count, weed dry weight, weed control efficiency and weed index. Weed count was found lower in August planting with black polythene mulch in open condition (30 DAP) and June planting with black polythene mulch in open condition (60 DAP). The lowest weed dry weight at 30 and 60 DAP were noticed in July planting under open condition and the highest in May planting without mulch in open condition.

Crop weather relations

Maximum temperature, forenoon and afternoon relative humidity and solar radiation recorded negative correlation with plant height, number of branches, days to first flowering, biomass yield and andrographolide content. Minimum temperature exhibited positive correlation with plant height at flowering stage, number of branches, biomass yields. The correlation with minimum temperature and andrographolide content was negative during most of the periods. Rainfall had negative correlation with biomass yield initially later on it influenced biomass positively.

Cost benefit analysis

A higher B: C ratio of 3.53 was obtained from May planting with black polythene mulching under shaded condition. Planting in July with paddy straw mulch under open condition recorded lower B: C ratio.

From the experiment it can be concluded that optimum growing condition, planting date and mulch for kiriyath is 50 per cent shade, 15th May and black polythene mulch respectively.

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Appendices

Appendix 1. Weekly weather data during experimental period

Std. Week No.	Date	Max. temp. (°C)	Min. temp. (°C)	Relative humidity (%)			Wind speed (Km/hr)	Mean Sunshine hours	Rainfall (mm)	Rainy days (No.)
				Morning	Evening	Mean				
19	06/5-13/5	35.5	24.7	85	58	72	1.8	6.8	15.2	1
20	14/5-20/5	35.0	25.8	88	57	72	1.8	6.6	16.2	1
21	21/5-27/5	33.9	25.2	87	61	73	1.8	3.4	26.2	2
22	28/5-03/6	31.1	24.0	94	76	85	1.4	2.9	113.2	7
23	04/6-10//6	30.8	24.1	92	75	84	0.9	1.3	60.6	5
24	11/6-17/6	30.2	23.9	97	79	88	0.8	0.9	151.2	5
25	18/6-24/6	31.7	23.6	94	78	86	4.1	4.1	104.4	6
26	25/6-01/7	29.4	22.4	96	83	90	1.3	1.3	291.8	7
27	02/7-08/7	30.1	22.7	96	77	86	0.9	1.8	77.1	7
28	09/7-15/7	30.3	22.9	94	75	85	0.5	1.5	97.5	4
29	16/7-22/7	30.9	22.1	95	77	86	1.4	2.1	171.1	6
30	23/7-29/7	31.6	23.0	93	68	31	1.6	5.2	30.3	5
31	30/7-05/8	31.2	23.9	94	75	85	1.7	5.1	87.1	2
32	06/8-12/8	29.9	23.6	95	73	84	1	3.5	80.8	4
33	13/8-19/8	31.0	23.4	96	79	88	0.8	3.5	83.8	3
34	20/8-26/8	30.1	23.1	97	76	86	0.8	2.1	97.7	3
35	27/8-02/9	29.4	23.1	95	80	88	1	2.9	143.6	6
36	03/9-09/9	31.7	23.6	94	77	86	0.7	4.4	56.5	5
37	10/9-16/9	32.4	23.0	96	78	87	0.7	3.9	91.9	4
38	17/9-23/9	30.6	22.2	95	71	83	1	4.2	211.5	5
39	24/9-30/9	31.2	22.9	94	70	82	0.2	4.1	39.0	2
40	01/10-07/10	31.4	22.8	95	72	84	0.1	4.1	61.1	2
41	08/10-14/10	31.9	22.8	93	71	82	0.1	4.5	14.6	3
42	15/10-21/10	30.9	22.2	95	79	87	0.1	3.9	56	3
43	22/10-28/10	32.0	21.5	91	64	78	0.3	6	50.5	2

44	29/10-04/11	33.5	22.7	83	50	70	1.4	7.4	29.9	2
45	01/11-07/11	32.3	21.9	85	61	73	2.2	5.7	3.5	1
46	12/11-18/11	32.8	20.8	93	57	75	0.6	6.7	0	0
47	19/11-25/11	33.8	21.6	92	55	73	1.6	6.8	25.5	2
48	26/11-02/12	32.0	22.5	82	61	71	5	4.3	11.5	2
49	03/12-09/12	32.8	21.0	89	58	73	1.8	7.3	0	0
50	10/12-16/12	32.7	21.4	87	56	72	1.8	5.1	0	0
51	17/12-23/12	32.3	21.5	67	42	54	9.2	9.1	0	0
52	24/12-31/12	32.8	20.3	68	36	52	7	9.4	0	0
1	01/1-07/1	33.2	19.8	75	41	58	3.9	8.8	0	0
2	08/1-14/1	32.7	21.8	73	39	56	6.7	7.4	0	0
3	15/1-21/1	33.8	20.7	63	33	48	6.9	8.6	0	0
4	22/1-28/1	34.1	21.4	68	39	53	4.3	8.1	0	0
5	29/1-04/2	34.3	20.5	48	26	37	7.3	9	0	0

CROP WEATHER RELATIONS ON YIELD, QUALITY AND WEED DYNAMICS OF KIRIYATH (*Andrographis paniculata* (Burm.f.) Wall. ex Nees.)

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ABSTRACT OF THE THESIS

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ABSTRACT

Kiriyath (*Andrographis paniculata* (Burm.f.) Wall. ex Nees., an important medicinal plant belonging to the family Acanthaceae, is known as "King of Bitters" and is traded in high volume and prioritized by State Medicinal Plant Board, Kerala. In medicinal plant cultivation, both yield and quality of produce are important. Variations in environmental conditions have great influence on production of active principles, and it is necessary to identify optimum growing conditions to grow cultivars with high yield potential. The present study was taken up in the Department of Agronomy, College of Horticulture,Vellanikkara to study the effect of variations in growing conditions, time of planting and mulching on yield, quality and weed dynamics of *Andrographis paniculata.* The trial was laid out in Randomized Block Design, replicated thrice. The treatments consisted of two growing conditions *viz*., open and 50 per cent shade, four dates of planting *viz*., 15^{th} May, 15^{th} June, 15^{th} July and 15^{th} August, and three mulching practices, *viz*., no mulching, paddy straw mulching and black polythene mulching.

Growing condition, planting date and mulching significantly influenced the plant height, number of branches and biomass yield of *Andrographis paniculata*. The highest biomass yield of 10.02 t ha^{-1} was observed under 50 per cent shade, May planting (12.87 t ha^{-1}) and mulching with black polythene (12.25 t ha^{-1}). Higher biomass yield was observed in the treatment combination of 15^{th} May planting under shade with black polythene mulching (15.67 t ha^{-1}) as brought out by analysis of interaction effects. It was on par with June planting with black polythene mulch under shaded condition (14.33 tha^{-1}).

Among different soil chemical properties studied, available K content of soil alone was significantly influenced by different treatments and was found higher in open condition (168.40 kg ha^{-1}), August planting (176.58 kg ha^{-1}) and with paddy straw mulching (188.08 kg ha^{-1}).

Physiological, chemical and biochemical parameters were also significantly influenced by growing condition, planting date and mulching. Total chlorophyll content at the time of harvest was higher under shade (2.23 mg g^{-1}), May planting (2.22 mg g^{-1}) and with paddy straw mulching (2.08 mg g^{-1}). Higher andrographolide content was recorded under 50 per cent shade (1.05%), August planting (1.04%) and with paddy straw mulching (1.05%). Analysis of interaction effects revealed that treatment combination of July planting under shade with paddy straw mulching recorded higher andrographolide content (1.17%) and was on par with August

planting with paddy straw mulching under shade (1.14%). Crop planted in June recorded significantly higher CGR at different growth stages. CGR was also found higher under black polythene mulch at different growth periods. Relative growth rate between 30 to 60 DAP was higher under open condition, June planting and under no mulch condition.

Soil temperature was higher under open, and with black polythene mulching whereas soil moisture was higher under shade, and with black polythene mulching throughout the crop period.

Weed density and dry weight were significantly influenced by the treatments. Lower weed dry weight was observed in August planting (at 30 DAP), and July planting (at 60 DAP). Black polythene mulching was the best treatment when weed control was considered, followed by paddy straw mulching. Highest weed control efficiency was recorded in July planting with black polythene mulch under open condition (99%), and July planting with paddy straw mulch under shade recorded lowest weed index (12.56%).

Maximum temperature, forenoon and afternoon relative humidity and solar radiation were negatively correlated with plant height, number of branches, days to first flowering, biomass yield and andrographolide content. Minimum temperature exhibited positive correlation with plant height, number of branches, and biomass yield at flowering stage. Rainfall had negative correlation with biomass yield initially, later on positive correlation was observed.

A higher B: C ratio of 3.53 was obtained with May planting along with black polythene mulching under shaded condition. From this experiment it can be concluded that planting of *Andrographis paniculata* in May - June under 50 per cent shade with black polythene mulch can be recommended for high yield, quality and profit. It is a suitable crop for growing in homesteads or as an intercrop in plantation crops.