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Impact of sowing and harvest times and irrigation regimes on the sennoside content of *Cassia angustifolia* Vahl

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ABSTRACT

Cassia angustifolia Vahl is known for the production of leaves and pod shells containing high-value glycosides (sennosides) with enormous medicinal properties to cure constipation in all over the world. However, data on its agricultural practices is limited. The present study aim to optimize the sowing time, moisture regime, and harvesting date at sub-tropical conditions for getting maximum marketable produce. Experiments were performed over two years (2016 and 2017) into two sets. First one comprised of seven dates of sowing, and second experiments having four moisture regimes and four dates of harvest. In sub-tropical north Indian conditions, 15 March was the best sowing date with highest biological yield (17.446 q ha^{-1}), sennoside content (2.18% in leaves and 3.26% in pods), and sennoside yield (45.943 kg ha^{-1}). The 20% available soil moisture with 90 days of harvesting time was suitable for the maximum biological yield of senna (17.296 q ha^{-1}). The maximum net return (67,989.0 Rs ha^{-1}) was observed at 20% available soil Moisture (ASM) condition at 90 days harvesting. Hence, the study recommended that the 15 March sowing date, 20% available soil moisture and 90 days harvest for the *Cassia angustifolia* Vahl. provide more income to the farmers and industry. Development of cost-effective package of practices leading to the quality assurance will encourage its cultivation and availability of raw material to the industry.

1. Introduction

Cassia angustifolia Vahl., which is also known as Indian senna or Tinneyvelley senna, a well known medicinal plant belongs to family Fabaceae. Senna is one of the most widely used herbal laxatives and finds great value in different systems of medicine (Rama Reddy et al., 2015; Tripathi, 1999). Its leaves are used for the treatment of habitual constipation and as a safe purgative which increases the peristaltic moment in the colon (Anon, 1966). Senna is also utilized for its antimicrobial, anticancer and antioxidant properties, and due to its potential uses in the number of drugs, senna finds a good demand in international market. India exports the plant of *Cassia angustifolia* Vahl. to various countries like Germany, Italy, Netherlands, Canada, Mexico, Australia, Japan, etc. Sennosides A and B isolated from leaves and pods ranged from 1.5 to 3.0% in these parts of the plant (Anon, 1985; Husain, 1992). It is commonly cultivated in warm climatic condition and marginal soils of India, Yemen and Hadramaut province of Southern Arabia and the opposite coast of Somalia. In India, it is one of 3 medicinal plants having the largest share in export, i.e., Senna, Isabgol and Opium poppy. It accounts for about 75% of international trade, whereas, 25% demand is met by Alexandrian senna (*Cassia acutifolia*). In India, annual production of *Cassia angustifolia* Vahl. is about 6000–7500 t of leaves and pods, 80% of which is exported and earning to the tunes of 350 to 360 million (Sastry et al., 2015). Senna cultivation is done in Rajasthan, Tamil Nadu, Gujarat, and in some parts of Andhra Pradesh of Indian states. Crop production especially the quality of senna is badly affected in traditional growing regions, leading to lots of quality complaints and the reduction in export. The important factors which influence the quality of produce are leaf blight by *Phyllostica* spp. and leaf spot by *Alternaria alternata* (Sastry et al., 2015) due to the rainy season crop as humid environment supports these problems. Senna cultivation is also possible in the sub-tropical plains of north India as a summer season crop during March to June (Dry period). This practice is useful for producing quality material with higher productivity per unit area and per unit time and for avoiding the fungal attack, which is more prevailed during the rainy season. However, very little information is available on optimum pre and post-harvest practices on this crop for these potential growing regions. Sowing time imposes a great role to obtain maximum yield. Therefore, it is important to find out the suitable date at which the sowing of senna

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seed is best for better yield, as well as the quality of this high-value medicinal crop. The performance of any crop is dependent on several environmental factors like temperature, humidity, rainfall, sunshine, and topographic condition of the cultivation area. Optimum sowing time is a must for gaining good seed germination as well as obtaining superior, and high-quality plant produce in the term of yield as well as secondary metabolites (alkaloids and glycosides). Too early and too late planting, both constitute poor germination and stunted crop growth. The optimization of irrigation is important to produce optimum fresh herb and seed yield because water is a major component of the fresh produce and affect both the quantity and quality of the crop. In the case of medicinal plants, water deficit may cause changes in the biomass yield and composition of their essential oils and secondary metabolites. The effects of different water regimes on yield, secondary metabolites, morphological and physiological characteristics of different medicinal plants have been reported so far. Moisture level in the soil for the cultivation of medicinal crops also has a very critical role in their quality parameter because moisture stress possesses a great influence on yield as well as sennoside content in senna as reported by Ahmed et al. (2014). Moisture stress found to increase sennoside content (Gupta, 1988). Besides the date of sowing and moisture level, harvesting time of a medicinal crop is also a very crucial parameter for quality standards. The leaf picking at different crop stages influences the sennoside content in senna leaves (Upadhyay et al., 2011). According to Tripathi, 1999, senna is a hardy crop and can be grown even in saline and rainfed condition. The proper time of sowing for senna to harvest the crop before the onset of monsoon as well as to get maximum yield with better quality along with proper utilization of irrigation water and date, at which it should be harvested, is not optimized yet for the subtropical plains of North India. Keeping in view above problems and prospects, experiments were conducted to optimize date of sowing, moisture regime and harvesting date for senna with the Objectives i) to improve the yield of leaves and pods, ii) to obtain high sennoside yield and iii) to find cost-effective agro-practice for senna cultivation under sub-tropical climatic condition.

2. Material and methods

2.1. Experimental site

The experiments were conducted for two consecutive years 2016 and 2017 at the experimental farm of the CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow, located at 26°5´ N latitude 80°5´ E longitude with an elevation of about 120 m above mean sea level under the sub-tropical plains of north- India. The soil of the experimental plot was sandy loam in texture having moderate fertility with 7.7 pH. Weather (temperature, relative humidity, and rainfall) prevailed during the experimental period of both the years has been presented in Fig. 1

2.2. Treatments and experimental design

Two field experiments were conducted consisting of different variables as described below.

2.2.1. Collection of seeds

Seeds used in experiments were collected from the experimental farm of CSIR-CIMAP, Lucknow. Seeds were belonging to variety “Sona” developed by CSIR-CIMAP, especially for northern Indian plains.

2.2.2. Experiment no. 1. Study on optimizing the date of sowing

The experiment comprises seven dates of sowing starting from 1st March, 8th March, 15th March, 22nd March, 29th March, 5th April and 12th April, were evaluated under randomized block design with three replications, in an individual plot size of 11.4 $m^{2.}$ Soil moisture level was about 60% (Available Soil Moisture) at the time of sowing. Before sowing, N, P and K applied (as recommended) through Urea, SSP and MOP respectively, was thoroughly mixed within the soil at the time of ploughing, and then plots were leveled. After that, seed sowing was done and, the line to line spacing was maintained at 45 cm apart. After 25 days of sowing, thinning was done to manage the plant to plant distance of 15 cm distant. All intercultural operations were carried out as per need. Harvesting was done at 90 days after sowing.

2.2.3. Experiment no. 2. Study on optimizing the moisture regimes and harvesting date

For optimization of moisture regimes, four levels of moisture, i.e., rainfed (no irrigation), 20% ASM, 40% ASM, and 60% ASM were imposed, and harvesting was done at four dates, i.e., 60, 75, 90, and 105 days after sowing. These treatments were evaluated in a split-plot design with four replications with a plot size of 11.4^{-2}. Sowing was done in the second week of March and line to line spacing was maintained at 45 cm apart and plant to plant distance was 15 cm (maintained by thinning after 25 days of sowing) and first irrigation was provided, after that, irrigations were applied as per treatments and 15 days before harvesting, withdrawal of irrigation was made.

In experiment 1, the main objective was to optimize the date of sowing with respect of already practiced date of harvest, whereas in the experiment 2, different moisture regimes were taken as main treatments aiming at optimization of moisture regimes with respect of period of maturity, as the quality influenced significantly by different moisture regimes in a number of medicinal crops. Hence, harvesting of crop at different period of growth and development was essential to optimize date of harvest for getting highest yield with superior quality of the produce.

2.3. Plant sampling and biometric observations

For recording observation on plant height, the number of branches, leaf area index, five plants were selected randomly (excluding border plants to avoid border effect) from each plot at the time of harvest. These plants were harvested from10 cm above the ground and data on the fresh weight of the plant, stem weight, leaf weight, pod weight, and flower weight (if present) were recorded per plant basis. After that, these plant parts were kept under the shade for drying and after 8–10 days (constant weight), dry weight was recorded. After drying, pod: leaf ratio and pod + leaf: stem ratio was also calculated.

2.4. Harvesting

In the first experiment, harvesting was done after 90 days of sowing with the respective date of sowing. In the second experiment, harvesting done at different dates as per the treatments (After 60 days, after 75 days, after 90 days and after 105 days of sowing). For the estimation of herbage yield, harvesting was done as per treatments, and the total weight of each plot was calculated, and weight of sampled plants was also added to herbage yield to the respective treatments. Then, the herb was left for drying in the shade for 8/10 days (to constant weight), dry weight of leaves, stem, and pod was recorded.

2.5. Sennoside determination

Chemical analysis was done through the HPLC method as described by Rama Reddy et al. (2015) with slight modification. Powdered samples of dry leaves and pods (300 mg) were extracted in 30 mL of 70% methanol in water by sonication (25 °C) for 20 min for three times. The samples were filtered through the 0.45 µm membrane before injection into the chromatography system. HPLC analysis was performed on a Waters HPLC system equipped with an SPD-M20 A photodiode array detector. For all separation symmetry, 98 C18 column (4.6 mm × 250 mm, 5.0 µm particle size) was used. The mobile phase consisted of (A) methanol:water:acetic acid (20:80:0.1, v/v/v) and (B)

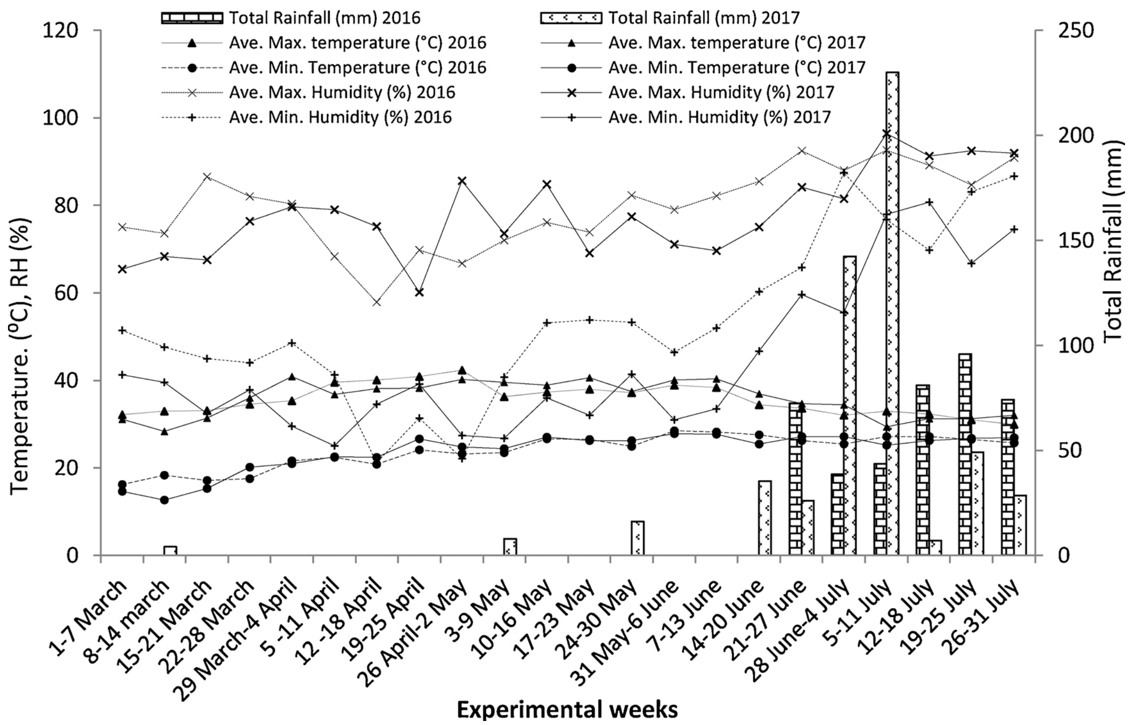

Fig. 1. Weather data of the experimental period.

methanol:water:acetic acid (80:20:0.1,v/v/v). The separation temperature was kept constant at 25 °C. The flow rate (1 mL/ min) and the sample volume was monitored at 285 nm. Peaks were assigned by spiking the sample with the authentic sample (standard) followed by the comparison of UV spectra and retention time.

2.6. Economics

Economics of both the experiments and all the treatments was calculated by average yield (leaf and pods) and the prevailing market price of inputs and output. Net return was calculated by subtracting the cost of cultivation from the gross return for each treatment.

2.7. Statistical analysis

The data was tabulated for experimental year 2016 and 2017 separately. The, average of both the years was analyzed statistically by using the analysis of variance technique for factorial randomized block design in the first and split-plot design in the second field experiment as suggested by Panse and Sukhatme (1985). The differences between treatment means were compared by the critical difference at 5% (*P = 0.05) level of significance.

3. Result and discussion

3.1. Effect of date of sowing

3.1.1. Morphological characters

Growth attributes of *Cassia angustifolia* Vahl. are influenced by the date of sowing (Table 1). Plant height, the number of branches per plant and Leaf Area Index (LAI) was reported to be maximum at the 15th March sown crop. There was an increasing trend in plant height, the number of branches as well as LAI from the 1st March onward and being highest at 15th March (78.33 cm) and after that, i.e., from 22nd March onwards there was a declining trend in all the growth attributes. Branches per plant were also found the maximum in 15th March sown plants (20/plant) whereas it was minimum at late sown (i.e., on 12 April) plants (14 branches/plant). Date of sowing had a significant effect on the pod: leaf ratio as well as on the pod + leaf: stem ratio. The pod: leaf ratio and the pod + leaf: stem ratio, both parameters were showed the similar trend in respect of different sowing dates. Pod: leaf ratio has recorded the minimum (1.15) in 1st March sown crop, and reported highest (1.65) in the 15th March crop. Similarly, the pod + leaf: stem ratio also recorded the maximum(1.92) in 15th March sown crop which was gradually decreased as the sowing date was delayed, which indicated that at delayed sowing, the stem portion became more in the plant in proportion to total marketable produce, i.e., pods and leaves.

Lower plant height, less number of branches/plant and lower LAI in the early sown senna crop may be due to its sun, heat-loving habit and it was sub-optimum in early March, due to cold weather (25 °C ± 2). The crop could not get favorable weather, and therefore, all morphological characters were low in early March than the 15th March planting whereas, late sowing, i.e., after 29th March temperature was higher than desirable. Thus, the crop was affected adversely. The crop sown between 15th March to 29th March may have benefitted by the better environmental condition like temperature, solar radiation because of that plant height was maximum in these dates and sowing too early or too late, both constitute poor plant growth and morphological characters. The variation in plant height, the number of branches/plant and Leaf Area Index (LAI) as affected by late or early sowing and transplanting has also been reported by a number of workers on different traditional and medicinal plants like Askar et al. (2013) and Saghayesh et al. (2014) on flax, Bagherpour et al. (2015) on *Cannabis*, Makawy (2012) on *Nigella sativa*, Mirzaei et al. (2016) on *Calendula officinalis*, Razzaque and Rafiquzzaman (2006) on the barley plant, Tahir et al. (2009) on *Triticum aestivum* L., and Tiwari and Meena (2016) on Chickpea plant.

3.1.2. Biological yield (leaf and pod in q ha^{-1}), sennoside content (%) and sennoside yield (kg/ha)

Data presented in Table 1 depicted that leaf and pod yield of senna was significantly affected by different dates of sowing. Maximum biological yield (leaf 10.1 q ha^{-1} and pod 7.3 q ha^{-1}) was recorded in the

Table 1
Morphological characters, biological yield, sennoside content and sennoside yield in leaf and pod as affected by date of sowing.

Date of sowing	Plant height (cm)	No. of Branch/ plant	LAI	Pod: Leaf	Pod + Leaf: Stem	Biological yield (q/ha)			Sennosidecontent (%)		Sennoside yield (kg/ha)		
						Leaf	Pod	Total yield (q/ha)	Leaf	Pod	Leaf	Pod	Total
1 March	70.00e	15.0d	3.2c	1.15f	1.58e	6.062f	4.255c	10.317e	1.98b	2.68c	12.0027d	11.4034d	23.4061d
8 march	74.55c	17.0c	3.2c	1.22e	1.66b	7.520e	4.530c	12.050d	2.00bc	2.81b	15.0400c	12.7293c	27.7693c
15 March	78.33a	20.0a	3.4a	1.65a	1.92a	10.121a	7.325a	17.446a	2.18a	3.26a	22.0637a	23.8795a	45.9432a
22 March	77.42b	19.0b	3.3b	1.55b	1.76c	9.580b	7.323a	16.903b	2.03c	2.80b	19.4474b	20.5044b	39.9518b
29 March	77.33b	19.0b	3.3b	1.55b	1.64d	9.235b	7.265a	16.500b	1.30d	1.58d	12.0055d	11.4787d	23.4842d
5 April	72.12d	17.0c	3.2c	1.50c	1.42f	8.211c	6.890b	15.101c	1.00e	1.30e	8.2110e	8.95700e	17.1680e
12 April	70.53e	14.0d	3.1d	1.47d	1.27g	8.000d	6.850b	14.850c	0.55f	0.89f	4.4000f	6.09650f	10.4965f
SEM	2.66	0.67	0.12	0.06	0.07	0.33	0.22	0.64	0.07	0.10	0.58	0.58	1.28
CD at 5%	5.79	1.47	0.28	0.13	0.15	0.73	0.50	139	0.16	0.22	1.28	1.26	2.80

Letters showing the difference (*P > 0.05).

15th March sown crop which was statistically at par with the herbage of 22[nd] March (leaf 9.6 q ha^{-1}, pod 7.3 q ha^{-1}) but significantly higher than the rest of the sowing dates. The yield was minimum (6.062 q ha^{-1} leaves and 4.255 q ha^{-1} pods) in the 1st March sown crop. Higher leaf and pod yield in 15[th] March might be due to favorable environmental conditions at the sowing time as well as during the growing period. Considerable yield decline as a result of sowing too early or too late has been reported in various food, medicinal, oil and other types of field crops. The Biological yield of plants (Leaf, Pod, seed, and grain) is positively affected by the date of sowing or transplanting of different crops. It has been proven by a number of workers which includes Askar et al. (2013), Ghobadi and Ghobadi (2010); El-Makawy (2012); Mirzaei et al. (2016); Saghayesh et al. (2014); Salmasi et al. (2006); Shakeri et al. (2015), and Upadhyay et al. (2015) who worked on different traditional as well as medicinal and aromatic plants like flax, *Coriandrum sativum, Nigella sativa* L., *Calendula officinalis*, *Anethum graveolense*, Cumin, and wheat, etc.

Sennoside content is always found higher in senna pods rather than its leaves irrespective of the date of sowing. The maximum sennoside content was 2.18% in leaves which was reported on 15 March sown crop, and it was at par with the 22[nd] March crop (2.03%) whereas significantly superior over all other dates of sowing. In pods, maximum sennoside content (3.26%) was reported on 15 March sown crop, and it was significantly superior over the rest of the dates of sowing under consideration. As the date of sowing delayed from 15[th] March onwards, sennoside content was decreased gradually and reported the minimum in 12th April seeded crop (0.55% in leaves and 0.89% in pods).

Medicinal plants show a marked variation in active ingredients during different seasons; as these have been widely attributed to alteration in environmental variables such as temperature and rainfall as reported by Soni et al. (2015). Variation in sennoside content may be due to the difference in environmental conditions at planting and harvesting time. The performance of any crop is also dependent on a number of environmental factors like temperature, humidity, rainfall, sunshine, and topographic condition of the production area. The early sown crop may not synthesize sufficient amount of secondary metabolites due to lack of stress faced by the crop during growth and development, similarly; the late seeded crop was harvested late, i.e., at the time of the onset of monsoon, due to which sennoside content was low because of lack of stress. Optimum sowing time is essential for gaining good seed germination as well as obtaining superior and the high-quality plant produce in terms of yield as well as secondary metabolites because the high temperature determined the considerably higher values of secondary metabolites (Radusciene et al., 2012).

Bright sunshine and low humidity prevailed during the summer season were beneficial for the 15th March sown crop and also accounts for the higher sennoside synthesis in leaves and pods. Due to higher herbage (leaf and pod) production and high sennoside content at 15th March sown crop, sennoside yield was also reported highest (45.94 kg ha^{-1}) on the 15th March sown crop, and it was significantly superior over early or delayed sowing. Because senna is a sun-loving crop, it requires bright sun to flourish (Sastry et al., 2015). Too early sowing can have an adverse effect on germination of seeds. Early sown seeds took more time to germinate as well as seedling growth rate was slower resulting which enhancement in the life cycle could have an impact on its yield as well as secondary metabolite content in leaf and pods. Whereas, late sown crop germinate well, but crop growth was stunted as well as due to late sowing harvesting time is also delayed, therefore; further arrival of the rains caused poor recovery of sennosides, and it was not as good as the 15th March sown crop.

3.1.3. Economics (cost of cultivation, gross return, and net return)

Cost of cultivation in 1st March, 8th March, 15th March, and 22nd March, were similar (23,500 Rs. ha^{-1}), and the number of irrigation applied was not varied in between 1st March to 22nd March (Fig. 2). After that, the crop which was sown at 29[th] March was harvested at 29th June, and due to delayed harvesting, the number of irrigation applied was less than the previous dates because of the onset of monsoon. Whereas, gross return fluctuated in different date of sowing due to differences in total biological yield obtain in the treatments of the different date of sowing. Gross and net return were maximum (91,759.0 Rs. ha^{-1}) and (68,259.0 Rs. ha^{-1}) respectively, in 15[th] March sown crop due to high biological yield.

3.2. Effect of moisture regimes and harvesting age of the crop

3.2.1. Morphological characters

The results presented in Table 2, showed that moisture regimes significantly influenced plant height, the number of branches/plant, Leaf Area Index (LAI), the pod: leaf ratio and the pod + leaf: stem ratio in different treatments. Tallest plants were recorded in the plots that were maintained at 60% ASM level and shortest plants were reported under the rainfed condition, whereas, the number of branches and LAI both growth parameters were found highest at 20% ASM. Due to more branches at 20% ASM, LAI was also higher in this treatment, whereas, it was minimum under rainfed condition (2.25) and superior over other higher moisture regimes, i.e., 60% and 40% ASM respectively. Pod: leaf and pod + leaf: stem ratios are crucial parameters to evaluate the crop growth in terms of relative growth of different vegetative parts. These ratios indicated the total pod yield in comparison to leaf yield at the particular stage of plant growth as well as the pod + leaf: stem ratio recorded the entire marketable produce in contrast to the inert stem portion of the plant. Moisture regimes greatly influenced these parameters. The pod: leaf ratio was found highest (1.42) in rainfed condition and the pod + leaf: stem ratio was also recorded the maximum (2.32) in the same treatment. Whereas, these values were minimum in

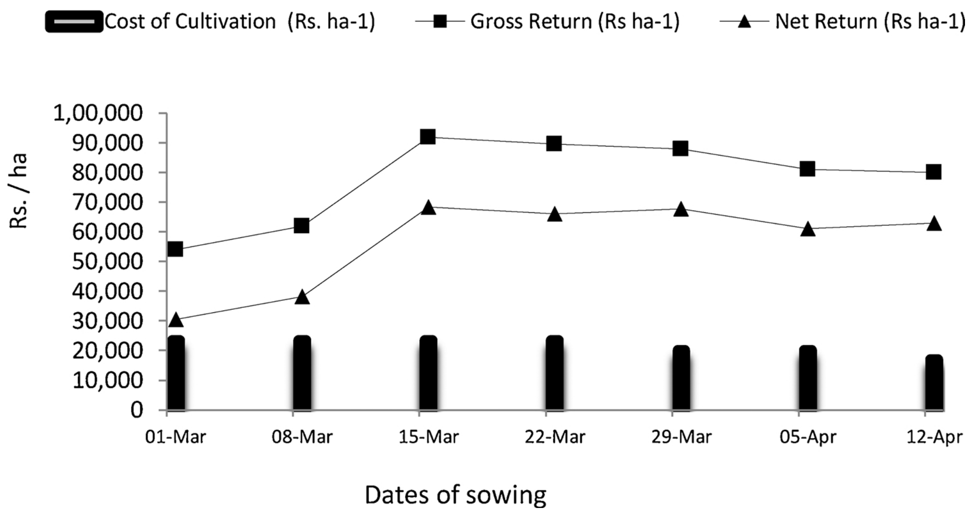

Fig. 2. Economics as affected by different dates of sowing.

60% ASM plots which indicated that upon increasing the irrigation regime, pod: leaf and pod + leaf: stem ratio get decreased.

The data recorded on growth parameters and morphological are given in Table 2. The progressive pattern of increase in height, the number of branches and leaf area index (LAI) was noted during the different growth stages of *Cassia angustifolia* Vahl. Significantly higher plant height was recorded at 105 days and branches were also found highest at 105 days of crop age, therefore showed the increasing trend with the advancement of crop growth. The LAI was found the maximum on 90-day crop age. It may be because plant height and the number of branches enhanced till 90 days without leaf fall and as a result, LAI was maximum (3.05) at 90 days age crop stage, and after that, there was a fall in LAI because of the fall down of older leaves. The same results on growth parameters have been reported by Prashar et al. (2011) on *Andrographis paniculata*. Harvesting date also posses its significant effect on the pod: leaf and pod + leaf: stem ratios. Pod: leaf ratio was lower in 60 days old crop and upon crop maturity; this value increased up to 90 days and then start to decrease. Then again declined (1.38) on further crop maturity, i.e., in 105 days old crop. For the pod + leaf: stem ratio, minimum values were recorded in 60 days old plants, and it increased up to 75 days crop stage (2.88). Upon further maturity of the crop, this value decreased, and it was 2.09 in 90 days old crop and the minimum (1.29) at 105 days of crop age.

The interaction effect of moisture regimes and crop age were significant. Plant height and number of branches were maximum at 105 days crop age; however, LAI was maximum at 90 days and 105 days crop age at 20% ASM.

The results showed that plant morphological characters were significantly influenced by moisture regimes. The plant height was correspondingly declined as the plant exposed to more stress condition. The decrease in shoot length under water stress condition was also reported by Anupama et al. (2005) on *Chrysanthemum* plant, Hojati et al. (2011) on *Carthamus tinctorious* L., Hussain et al. (2008) on *Helianthus anus* L., Khater et al. (2005) on *Mentha piperita* L., Yousef (2002) on the Chamomile plant, and Yousef et al. (2013) on *Echinacea purpurea* L. They all reported that water deficit during the vegetative period can result in shorter plants. Such decrease in plant height in response to water stress may be due to the decrease in cell elongation resulting from water shortage, which led to a decrease in each of cell turger, cell volume and eventually cell growth and due to blocking up of xylem and phloem vessels thus hindering translocation. The influence of water deficit on branches/plant and LAI has been demonstrated by Alaei et al. (2013) on *Dracocephalum moldavica*, Gerami et al. (2016) on *Oreganum vulgare* L., Hassan et al. (2013) on *Rosmarinus officinalis* L. and Naomi et al. (2014) on *Salvia officinalis*, etc. The highest value of pod:leaf and the pod + leaf:stem ratio in rainfed plots may be because of lack of moisture, due to which plant height, the number of branches and leaves were very less, whereas, pod yield was more in comparison to leaf yield, due to which, both the ratio was significantly higher in rainfed plots.

Water availability plays the crucial role in plant growth and development but more water may also become harmful for optimum plant growth whereas poor growth during rainfed condition, can be attributed to its direct effect on cell division which arose from the reduction in nucleic acid synthesis which enhances its break down (Ashraf et al., 1996). Therefore, 20% ASM condition provided optimum moisture to the plant, and the maximum number of branches has been reported in this treatment.

3.2.2. Biological yield (leaf and pod in q ha^{-1}), sennoside content (%) and sennoside yield (kg/ha)

Leaf yield: The irrigation regimes demonstrated the significant effect on leaf yield with maximum leaf yield in 60% ASM (7.66 q ha^{-1}) (Table 3). The decline in moisture content reduced the leaf yield. At 60 days harvest, leaf yield was 4.275 q ha^{-1} which was increased as the crop harvesting was delayed and reached the maximum at 90 days (8.386 q ha^{-1}). The fallen off of leaves after maturity may be the possible reason for the lower leaf yield at higher crop age.

Pod yield: Pod yield (4.826 q ha^{-1}) was maximum at 20% ASM, and at 90 days of crop harvesting (5.6477 q ha^{-1}) (Table 3). After 90 days, there was a decline in pod yield (4.09825 q ha^{-1}). Interaction effect showed that the maximum pod yield (7.435 q ha^{-1}) in 20% ASM at 90 days plant age, however, a minimum value reported in rainfed plots at 105 days of crop age.

Maximum yield in 20% ASM at 90 days crop age may be attributed to optimum moisture condition (20% ASM) in fields, which promoted better growth and harvesting at 90 days, prevented the leaves and pods senescence due to over maturity of the crop. Over maturity reduces the crop yield and has been worked out by several workers on different medicinal and aromatic plants. Ahmed et al. (2000) found that the increment in yield was directly related to the increase in the number of irrigation in faba bean. Halepyati et al. (2002) reported that the increasing irrigation water recorded an increase in growth parameters and fresh weight while working on tuberose plants. This decrease in leaf yield attributes under the highest irrigation interval, and rainfed condition to that water stress changes the hormonal balance of mature leaves, thus enhancing leaf senescence and hence the number of active leaves decreased. Further, the leaf area was reduced by water shortage, which was attributed to its effect on cell division and lamina expansion, when the leaf level decreased the light attraction, and CO_2 diffusion inside the leaf decreased, and a total capacity of photosynthesis

Table 2
Growth attributes (height, branches, LAI, pod: leaf, pod + leaf: stem) as affected by moisture regimes and harvesting age of the crop.

Date of harvest																									
Moisture regimes	Plant Height(cm)					No. of Branches/plant					LAI					Pod: Leaf					Pod + Leaf: Stem				
	60	75	90	105	Mean	60	75	90	105	Mean	60	75	90	105	Mean	60	75	90	105	Mean	60	75	90	105	Mean
60% ASM	56.0a	78.0a	85.8a	93.0a	78.19 a	11.8b	17.8b	20.0a	20.3b	17.48 b	2.3a	2.58b	3.1b	3.1b	2.77 b	0.07c	0.57d	1.33d	1.40b	0.84 b	1.40b	2.20c	1.50d	1.18c	1.57 d
40% ASM	53.0b	72.5b	80.5b	90.0b	74.00 b	12.3a	18.5a	20.1a	20.5b	17.85 b	2.2b	2.7a	3.2b	3.2b	2.82 b	0.07c	1.13c	1.33c	1.45b	0.99 a	1.40b	2.66b	1.69c	1.30b	1.76 c
20% ASM	52.5b	69.3c	78.3c	88.2c	72.06 c	12.5a	18.5a	21.3a	21.5a	18.45 a	2.2b	2.5b	3.5a	3.5a	2.92 a	0.16b	1.66b	1.62b	1.66a	1.28 d	1.40b	3.33a	2.03b	1.53a	2.07 b
Rainfed	49.5c	56.3d	60.2d	63.3d	57.30 d	8.5c	10.5b	12.3b	13.2c	11.13 c	2.1c	2.2c	2.4c	2.3c	2.25 c	0.18a	2.00a	2.50a	1.00c	1.42 c	1.62a	3.33a	3.16a	1.17c	2.32 a
Mean	52.75	69.0	76.18	83.62		11.27	16.33	18.43	18.88		2.20	2.49	3.05	3.03		0.12	1.34	1.69	1.38		1.45	2.88	2.09	1.29	
			SEM	CD at 5%				SEM	CD at 5%				SEM	CD at 5%				SEM	CD at 5%				SEM	CD at 5%	
Moisture(M)			2.10	5.14				0.83	2.03				0.15	0.38				0.10	0.26				0.13	0.32	
Date of Harvest (D)			1.51	3.11				0.38	0.79				0.11	0.23				0.10	0.21				0.12	0.24	
M × D			3.02	6.23				0.77	1.59				0.22	0.46				0.21	0.43				0.24	0.49	

Letters showing the difference (*P > 0.05).

decreased. Whereas due to water stress condition pods were mature earlier in rainfed plots.

Data presented in the Table 3 revealed that dry weights were progressively reduced by increasing stress conditions. The results reported by Khalid (2006) on *Ocimum* spp., Naomi et al. (2014) and Sonmez and Bayram (2017) on *Salvia officinalis* L., Said Al-Ahl et al. (2009) on *Origanum vulgare*, also supports the finding. The reduction in biological yield attributed to the accelerated senescence and shedding off leaves under water stress (Faisal et al., 2000). This result could be due to that one of the first signs of water shortage was the decrease of turger which resulted in a decline in growth and development of the cell, especially in leaves (Alishah et al., 2006). In general, water stress reduces plant growth through inhibition of various physiological and biochemical processes, such as photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism, and hormones (Khalil and El-Noemani, 2012 and Bahreininejad et al., 2013).

Different stages of harvesting had a significant effect on the dry matter yield, which includes both leaves and pods in case of Indian senna. There was a continuous pattern of increase in dry leaf and pod yield from pre-flowering (60 days of crop age) to the pod setting stage (90 days of crop age) of harvesting. The reduction in herbage (leaves and pods) yield after 90 days crop age was mainly due to lesser dry matter yield per plant and senescence of leaves and pods at later stages of crop growth (Pandey et al., 2003; Maheshvari et al., 2002). The proper time of harvesting plays a crucial role in crop quality. Therefore, the crop should be mature uniformly to obtain maximum yield. Otherwise, the delay in harvest increases the production cost and occupation of land for more time without any extra benefit. On the other hand, premature harvesting decreases the crop yield as well as the quality of the produce.

Sennoside content in leaves and pods, as affected by moisture regimes and crop age of harvest has been presented in Table 3. Sennosides were always found higher in pods as compared with leaves irrespective of moisture regimes and plant age. Moisture regimes possess its significant influence on sennoside content. The sennoside content was highest (1.67% in leaves and 2.46% in pods) in rainfed condition irrespective of plant age. Higher sennosides in more water stress condition attributed to several factors. The development of plants, their yield and their physiological, as well as biological characteristics, are strongly altered by the different types of stresses imposes by their surrounding environment. The level of secondary metabolite also increases due to water stress faced by plants. In addition to this, active oxygen species (AOS) also formed due to the oxidative stress, which arises due to water stress condition in plants and to protect from AOS. Therefore, plants have developed the enzymatic or non-enzymatic complex antioxidant system. As a defense mechanism secondary metabolites accumulated in plants under water stress conditions (Liu et al., 2011). There are many reports on increased level of secondary metabolite production during water stress condition in medicinal plants such as *Bupleuri radix* (Zhu et al., 2009), *Rehmannia glutinosa* (Gaertn.) (Chung et al., 2006), *Papaver somniferum* (Szabo et al., 2003), *Scrophularia ningpoensis* (Wang et al., 2010).

The low concentration at 60 and 75 days crop may be due prematurity of the plant with the lower synthesis of sennosides (Table 3). Results indicated that optimum accumulation of sennosides occurred at 90 days crops after that environmental condition was not suitable for their accumulation. Generally, the hot sunny days poses stress to the plant leading to the synthesis of secondary metabolites. Decline sennoside content after the onset of rains (105 days after sowing) probably due to the reduction in stress. Therefore, at 90 days when plants reach their maximum growth is suitable time to harvest for quality produce. Similar effect of plant age on secondary metabolites synthesis were also reported previously for various plants such as *Hypericum perforatum* (Azizi, 2008), *Fritillaria cirrhosa* (Konchar et al., 2011), *Andrographis paniculata* (Kumar and Kumar, 2013; Seema Nemade et al., 2003; Bhan et al., 2006), *Catharanthus roseus* (Siribel et al., 2004) and *Bacopa*

Table 3
Biological yield (leaf and pod), sennoside content and sennoside yield as affected by moisture regimes and harvesting age of the crop.

Days of harvest	Leaf					Pod					Total (Leaf + Pod)				
Moisture regimes	60	75	90	105	Mean	60	75	90	105	Mean	60	75	90	105	Mean
Biological Yield (q/ha)															
60% ASM	4.990a	7.221a	10.033a	8.4000a	7.661a	0.765c	2.990c	5.326c	4.657c	3.434b	5.755a	10.211b	15.359b	13.057b	11.095b
40% ASM	4.825a	7.200a	9.9210ab	7.8220b	7.442b	0.778c	3.034c	5.443b	4.983b	3.559b	5.603ab	10.234b	15.364b	12.805b	11.001b
20% ASM	4.755b	7.180b	9.8610b	7.7540b	7.387b	0.920b	4.434a	7.435a	6.518a	4.826a	5.675a	11.614a	17.296a	14.272a	12.214a
Rainfed	2.530c	3.131c	3.6330c	3.1370c	3.107c	1.010a	3.364b	4.387d	0.235d	2.249c	3.540c	6.495c	8.0200c	3.3720c	5.356c
Mean	4.275	6.183	8.362	6.77825		0.86825	3.4555	5.64775	4.09825		5.143	9.638	14.009	10.876	
			SEM	CD at 5%				SEM	CD at 5%				SEM	CD at 5%	
Moisture(M)			0.29	0.72				0.17	0.43				0.25	0.61	
Date of Harvest(D)			0.20	0.41				0.15	0.32				0.26	0.54	
M × D			0.40	0.82				0.31	0.64				0.53	1.09	
Sennoside (A + B) content (%)															
60% ASM	1.20c	1.45d	1.75c	0.80c	1.3c	1.85c	2.10c	2.32c	1.00c	1.81c	–	–	–	–	–
40% ASM	1.33b	1.58c	2.02b	0.82c	1.43b	1.99b	2.28c	2.66b	1.09c	2.00b	–	–	–	–	–
20% ASM	1.38b	1.89b	2.20a	0.99b	1.61a	2.01b	2.49b	3.25a	1.25b	2.25a	–	–	–	–	–
Rainfed	1.40a	1.95a	2.25a	1.08a	1.67a	2.22a	2.85a	3.36a	1.44a	2.46a	–	–	–	–	–
Mean	1.3275	1.7175	2.0550	0.9225		2.0175	2.4300	2.8975	1.1950		–	–	–	–	
			SEM	CD at 5%				SEM	CD at 5%						
Moisture(M)			0.10	0.25				0.10	0.25						
Date of Harvest(D)			0.09	0.20				0.12	0.26						
M × D			0.19	0.40				0.25	0.52						
Sennoside (A + B) Yield (kg/ha)															
60% ASM	5.988b	10.470b	17.557c	6.720b	10.1837c	1.415c	6.279c	12.356c	4.657c	6.1767c	7.4032c	16.749d	29.913c	11.377b	16.3605c
40% ASM	6.417a	11.376a	20.040b	6.414b	11.0617b	1.548c	6.917c	14.478b	5.431b	7.0935b	7.9654b	18.293b	34.518b	11.845b	18.1553b
20% ASM	6.562a	13.570a	21.694a	7.676a	12.3755a	1.849b	11.040a	24.163a	8.147a	11.2997a	8.4111a	24.610a	45.857a	15.823a	23.6752a
Rainfed	3.542c	6.105c	8.174d	3.387c	5.3020d	2.242a	9.587b	14.740b	0.338d	6.7267c	5.7842d	15.692c	22.914d	3.725c	12.0288d
Mean	5.62725	10.38025	16.86625	6.04925		1.7635	8.45575	16.43425	4.64325		7.3909	18.8360	33.3005	10.6925	
			SEM	CD at 5%				SEM	CD at 5%				SEM	CD at 5%	
Moisture(M)			0.27	0.67				0.31	0.76				0.56	1.37	
Date of Harvest(D)			0.29	0.61				0.31	0.64				0.49	1.01	
M × D			0.59	1.23				0.62	1.29				0.98	2.03	

Letters showing the difference (*P > 0.05).

monnerii (Phrompittayarat et al., 2011).

The sennoside yield obtained by multiplying the yield of leaves and pods with their respective sennosides content (Table 3). It was found that the highest sennoside content reported in 90 days old crop in rainfed condition (both leaves and pods) but, crop growth was not satisfactory. Due to water shortage, leaves and pods senescence and fallen on the ground as well as production is also very flat in rainfed condition irrespective of crop age, due to which sennoside yield is also get decreased in rainfed plots, which may be attributed to slow growth during rainfed condition irrespective of plant age. Highest sennoside yield (12.3755 kg ha^{-1} in leaves and 11.2997 kg ha^{-1} in pods) was obtained in 20% ASM plots, which is attributed to more biological (leaf and pods) yield in 20% ASM in comparison to all other high and low moisture plots irrespective of the date of harvest. Lowest sennoside yield in leaf (5.3020 kg ha^{-1}) was reported in rainfed plots and in pods lowest value was reported in 60% ASM. Mean sennoside yield was lowest (leaves 5.627 kg ha^{-1}, pod 1.763 kg ha^{-1}) at 60 days crop age and reported highest (leaves 16.866 kg ha^{-1}, pods 16.434 kg ha^{-1}) at 90 days crop age due to high biological yield and superior quality in leaves as well as pods at this stage. Whereas, at 105 days, sennoside yield was decreased (6.0492 kg ha^{-1} leaves and 4.643 kg ha^{-1} pods) due to leaf senescence and decrease leaf and pod yield as compared to 90 days old plants.

Interaction of moisture regimes and days of harvest had a significant effect on sennoside yield. Maximum sennoside yield (21.694 kg ha^{-1} in leaves and 24.163 kg ha^{-1} in pods) was reported in 20% ASM at 90 days of crop age.

3.2.3. *Economics (cost of cultivation, gross and net returns)*

The cost of cultivation, gross and net returns (Rs. ha^{-1}) were worked out as per different treatments and have been presented in Fig. 3. Cost of cultivation was varied with irrigation applied in different treatments and crop maturity period. These parameters affect harvesting cost, the application of pesticides as per different treatments, etc. The cost of cultivation was maximum (29,875.0 Rs. ha^{-1}) in the highest moisture regimes, i.e., 60% ASM because more number of irrigation was applied during the entire cropping period, whereas the lowest cost of cultivation was reported in rainfed plots (12,000.0 ha^{-1}) irrespective of days of harvest. It is due to that no separate irrigation was provided but only rain. Gross return was highest in 20% ASM condition, and it was attributed to the highest biological yield (leaves and pods) obtained in this treatment whereas the lowest gross return was reported in rainfed condition irrespective of the date of harvest.

The lowest cost of cultivation was in rainfed condition because irrigation was not applied in these plots but gross and net returns both were lowest in these plots because due to rainfed cultivation there was very less biological yield both in leaves as well as pods. Whereas, the highest net return was obtained at 90 days of crop age because upon over maturity of the crop, biological yield decreases and therefore net return also decreases. Therefore, in terms of highest gross and net returns, harvesting of 20% ASM plots at 90 days was the best treatment for obtaining maximum benefit from this highly valuable medicinal plant.

4. Conclusion

The findings of the present investigation suggest that *Cassia angustifolia* Vahl. can be successfully cultivated in northern Indian plains by optimization of date of sowing, moisture regimes along with date of harvest, with higher net returns to the farmers and the industrialists. Our studies indicated that the suitable time for senna sowing is mid-March (15–22 March). The bright sun in this period leads to higher biological yield (17.446 q ha^{-1}) with maximum sennoside content (2.18% in leaves and 3.26% in pods). Additionally, sowing at this time minimizes the losses of the secondary metabolites due to rains at the time of harvesting which makes the crop more economical to the farmers. Apart from sennoside content and yield, net return was also reported highest in 15th March sown crop. Results also suggest that the optimum moisture for senna cultivation is about @20% ASM, at 90 days of crop maturity. These conditions provided the highest biological yield (17.296 q ha^{-1}) and sennoside yield (45.857 kg ha^{-1}). Though the rainfed conditions bring highest sennoside content (2.25% in leaves and 3.26% in pods) but low herbage was obtained due to senescence of leaves and pods. Hence, in rainfed conditions, lowest sennoside yield was observed, whereas, due to highest biological and sennoside yield in 20% ASM and 90 days harvest, net return was maximum in the above said moisture regime and crop maturity. Therefore, sowing in mid-March, at 20% ASM and 90 days crop ages are suitable for the optimum biological yield, sennoside content and net profit.

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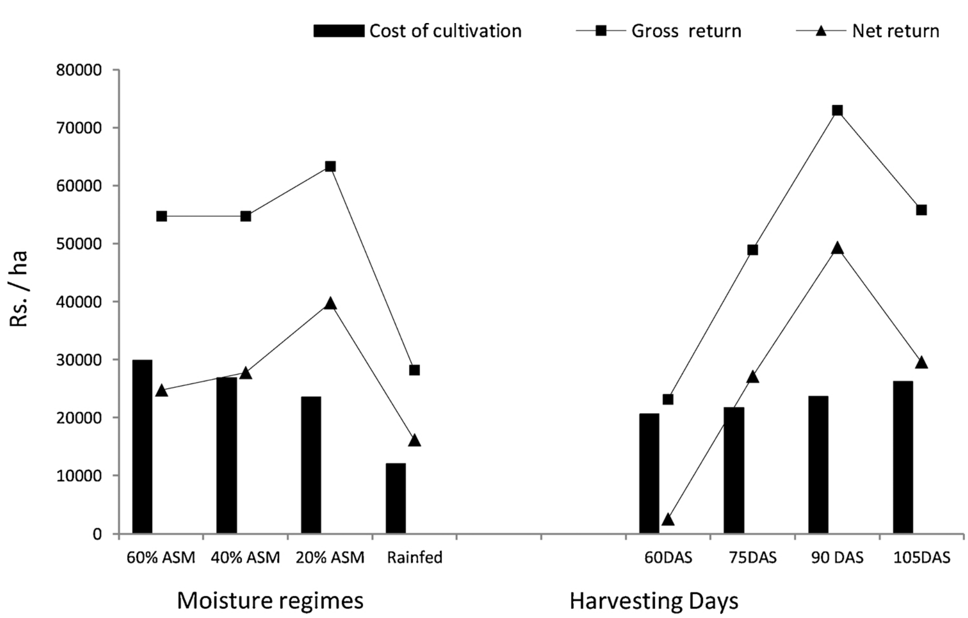

Fig. 3. Economics as affected by moisture regimes and harvesting age of the crop.

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