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Physiological Behaviour and Yield Evaluation of Agronomic Crops Under Agri-horti-silviculture System

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Abstract An agri-horti-silvicultural model involving poplar (*Populus deltoides* Bartr. Ex Marsh.) as timber tree component, fruit trees and agronomic crops viz, turmeric (*Curcuma longa* L.) and moong (*Vigna radiata* L.) were evaluated for yield. Net photosynthesis, stomatal conductance and transpiration in both crops were higher in open areas than in shaded ones. Agronomic crops showed initially better performance under partial shade in yield and yield contributing parameters, and decreased as poplar canopy advanced in age. Changes in these parameters showed inverse relationship with canopy age and vice versa with more yield reduction under fifth year old canopy followed by preceding years and control. The results of studies on the micro-climatic interaction and resultant effect on physiology, yield and economics of agronomic crops under poplar tree canopy are presented in this paper. The transpiration (E) rate of crops was lowest under shade conditions irrespective of the crop used in the experiment leading to more water use efficiency in the shade conditions than in open. There was gradual reduction in crop yield with advancement of age but the economic benefits of intercropping were two to three times higher than traditional crop rotation. It is suggested that to minimize resource competition and improve physiological processes of crops, canopy management is essential to ensure better yield under poplar-based agri-horti-silvicultural system.

Keywords Inter-Cropping, Agronomic Crops, Poplar, Agroforestry, Shading Effect, Physiology, Yield

1. Introduction

Agroforestry can be defined as an approach to land use that incorporates trees into farming systems, and allows for the production of trees and crops or livestock from the same piece of land in order to obtain economic, environmental, ecological, and cultural benefits[1]. Diversification of existing farming systems by developing suitable agroforestry models seems to be the need of the day to cope up with ever increasing demand for diversified products. Diversification in traditional crop rotation (rice-wheat) has been accorded a high priority in irrigated agro-ecosystem of North-western states of India due to several socio-economic and ecological problems i.e., insufficient storage space for rice and wheat produce, declining soil health, depleting underground water resources, indiscriminate use of agrochemicals, etc. Farmers have tried alternatives to rice-wheat rotation like other crops (pulses, oilseed, fruits, vegetable, etc.), poultry, pisciculture, piggery, dairy, etc. but much success has not been achieved because of inadequate marketing, technical and financial support[2].

Agroforestry offers an economical and ecologically viable option for large scale diversification in agriculture on one hand and environmental amelioration on the other. The increasing population and rapid industrialization has increased pressure on the traditional forests for timber and other related wood products. Therefore, to save forests and meet the growing demands of wood, there is need for large scale plantations of fast growing tree species outside forests to make country self reliant in its timber requirements. Fast growing tree species with rotation of less than ten years like poplar, eucalypts, leucaena, casuarina, willow, etc. have gained preference due to their higher productivity and acceptability in the market. On-farm timber tree plantations can also benefit from the global environmental facilities like carbon trading[3,4].

Agricultural crop inputs in India are subsidised (varies from state to state) and governments are under pressure to phase out the subsidies to reduce the fiscal burden. Therefore, farmers are looking for competitive alternative options, and short rotation timber trees based integrated systems have been found remunerative than traditional crop rotations. North-western Indian states have the potential to meet the industrial requirements of the country and state Governments are supporting farmers through liberalized harvesting and marketing policies for on-farm timber. Farmers are looking for species, which are low energy requiring with high water and nutrient use efficiency. *Populus deltoides* is one such deciduous species, which is economically the most important

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being grown under agroforestry plantations in Punjab, Haryana, Uttar Pradesh, Uttrakhand, Himachal Pradesh and Bihar states of India[5-7]. Poplar based agroforestry offers a better livelihood to farmers due to relatively low input costs, flexible labour requirements, compatibility with understorey crops, higher productivity/profitability, etc. Poplar based agroforestry has been found to give better economic returns than sole annual crops[5,8].

Traditionally, agro-forestry had its origins in developing nations where high population densities coupled with scarce land resources have required that concurrent food and wood production may be produced on the same land base with little compromise on principal of sustainability. Furthermore, tree- based inter-cropping systems can result in more diversified economies for both short- and long-term products and provide a market for both agronomic and forest crops. Inter-cropping systems can also play a vital role in sequestering carbon below- and above-ground plant components, thereby addressing present and critical societal concerns about global climate change[1,9-11]. With these potential benefits, successful tree based inter-cropping systems will minimize competitive interactions between non-woody (annual agricultural crop) and woody (tree) components while exploiting beneficial interactions between these components. Increasing our understanding of these interactions will provide a scientific basis for both improvement and adoption of tree- based inter-cropping systems.

Apparently, integration of trees and crops leads to complex interactions among the components at various bio-physical domains such as light, space, water, nutrients, etc. The complementary effect among these factors is the key for success of an agroforestry system. The modifications in micro-environment due to growing of trees, directly or indirectly influence various vital physiological processes of the plants grown under tree canopy. Generally, Photosynthetically Active Radiation (PAR) and temperature (air/soil) are reduced, while the humidity is increased. Among these, PAR is important as the radiant energy captured by plants is utilized in the photosynthesis, which is the primary process governing biomass production and yield. Therefore, investigations on the physiological processes especially those related to photosynthesis are critical for understanding the plant growth under the canopy of trees. This article deals with the physiological response of under-storey crops and biological/economic performance of turmeric and moong crops under poplar-fruit based agroforestry system.

2. Materials and Methods

The study was conducted in the experimental area of Department of Horticulture, Punjab Agricultural University (PAU), Ludhiana located at 30^o 45 N latitude and 75^o 18 E longitudes at an elevation of 247m above mean sea level. The climate is sub-tropical with dry season from late September to early June. The area received an annual rainfall of 704 mm. The experimental plantation was taken up in January, 2006 involving four fruit trees species (Kinnow, guava, peach and plum at 6 x 6m spacing) and poplar trees (6 x 6m, N-S direction) grown alternatively. Understorey crops such as turmeric (*Curcuma longa* L.) and moong (*Vigna radiata* L.) were sown in the month of April in the inter-row spaces of two ages of poplar trees (G48) planted in north-south direction in completely randomized design with three replications (each row as replicate of 30m). Arable crops, turmeric and moong grown in tree less plots served as control. The recommended agronomic practices of PAU were followed throughout the growing period of the crop. The variables measured include photosynthetic active radiation (PAR), stomatal conductance and intercellular CO2, transpiration rate with portable photosynthesis system (CID 340, CID Inc., USA). The diurnal variation in these parameters was measured to arrive at average values. The canopy characteristics such as the light interception and leaf area index of poplar trees was measured using digital lux meter and canopy analyser (CID 310, CID Inc, USA), respectively. The per cent light intercepted by trees was calculated as the reduction in the average light intensity under tree cover over control. The crop yield and yield contributing parameters were recorded on 1mx1m quadrat basis to extrapolate the yield on hectare basis. Since the fruit plants were small and under canopy of poplar therefore they were not included for observations. Average girth at breast height and height of the plants at the age of five years was 83cm and 22.4m, respectively. Accordingly the economics was worked out for comparison. Systat-11, statistical software[12] was used for computation of descriptive.

3. Results and Discussion

3.1. Physiology of Under-Storey Crops Grown Under Poplar Canopy

The average photosynthesis of crops (turmeric and moong) grown under poplar plantation varied with the light interception. Among the physiological parameters, the Pn was maximum under control conditions in all the crops with the maximum value of 18.15 $\mu molm^{-2}s^{-1}$ in moong, followed by turmeric 5.53 $\mu molm^{-2}s^{-1}$ and. The Pn/E ratio, which indicates water use efficiency (WUE) was higher in 4th year poplar plantation in turmeric (0.0046) and 0.0035 for moong in 5th year old plantation (Table 1). The minimum values 0.0029 and 0.0031 of WUE were recorded in turmeric and moong, respectively grown under open conditions. The carboxylation efficiency (P_n/C_i), which indicates the productivity potential, was higher in open grown crop and minimum in turmeric (0.0103) and moong (0.0243) grown under 5th year plantation. The photosynthesis capacity is influenced by stomata, which is sensitive to the environmental variations, especially air temperature and water stress. Under these circumstances, the stomatal functioning appears to be major limitation to CO_2 influx, causing reduction in photosynthesis during noon. Photosynthesis is a physiological process that is affected by the environmental factors. All the under-storey crops in general show changes in photosynthetic rate with a maximum photosynthetic activity during afternoon depending upon prevailing weather conditions during their growth period. Proportional changes in photosynthesis rate in rhizomatous crops with available PAR has been reported earlier, which was not observed in open condition[13,14]. Yield in arable crops are attributed to the reduction in light transmission under canopy[15-17]. It is evident from the Fig. 1 that all parameters viz., net photosynthesis rate, transpiration and stomatal conductance were higher in the open except internal Co_2, which was higher in the shade (5 years old plantation). The transpiration (E) rate was minimum under shade conditions irrespective of the crop used in the experiment. Maximum WUE (Pn/E) was recorded under open conditions because there was decline in photosynthesis under shade conditions. Moong crop recorded better net photosynthesis, stomatal conductance as compared to turmeric (Fig. 1). Carboxylation efficiency (CE) of under-storey crops started declining after four years of poplar plantation as there was more decline in photosynthesis in shade and also there was increase in inter-cellular carbon. Under heavy shade, the photosynthetic rate declined because carboxylation efficiency decline after shading. High Ci suppressed the response of conductance to sunlight. However, there was a large response of conductance to light at low Ci, indicating an interaction between the effects of light and CO_2 on stomata.

Table 1. Eco-physiological parameters recorded in turmeric and moong grown under poplar trees

*Parameters/ Canopy age	PAR ($\mu molm^{2}s^{-1}$)	Photosynthesis rate - Pn ($\mu molm^{2}s^{-1}$)	T_{air} (° C)	RH (%)	WUE (Water use efficiency)	Carboxylation efficiency	C_{int}/C_{atm}
Moong (2008)							
IV year*	-	-	-	-	-	-	-
III year	433.56	5.62	34.27	69.74	0.0024	0.0188	0.78
Control	700.32	15.23	36.81	77.30	0.0029	0.054	0.85
Turmeric (2008)							
IV year	497.88	2.31	32.19	81.99	0.0013	0.0063	0.93
III year	654.07	3.50	33.15	72.25	0.0036	0.0100	0.84
Control	875.59	5.50	36.56	69.88	0.0022	0.0173	0.80
Moong (2009)							
V year	318.71	9.39	34.82	72.54	0.0035	0.0243	0.82
IV year	468.49	13.14	37.29	65.38	0.0033	0.0370	0.86
Control	715.77	18.15	41.04	58.76	0.0031	0.0603	0.60
Turmeric (2009)							
V year	237.03	3.55	31.00	62.50	0.0032	0.0103	0.62
IV year	354.94	4.74	34.29	54.45	0.0046	0.0162	0.58
Control	807.29	5.53	37.11	60.37	0.0029	0.0183	0.54

*Moong crop failed due to heavy rains after crop sowing

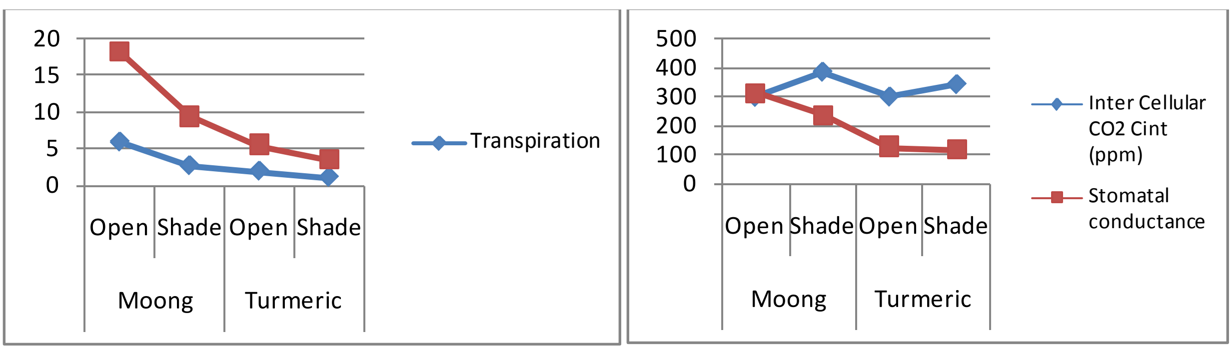

Figure 1. Physiological parameters of turmeric and moong as affected by shade of poplar tree canopy and open

3.2. Diurnal Variation in Physiological Parameters of Crops and Microclimate Modification under Poplar Trees

Reduction in solar radiation influences the physiological processes more importantly the photosynthesis. Plants responses to light include adaptation at physiological and biochemical levels[18]. Plants have ability to adapt to different light regimes (quality/quantity) through changes in physiological behaviour. Rate of photosynthesis/ transpiration/stomatal conductance was proportional to PAR received. The diurnal variations in eco-physiological parameters recorded in under-storey crops viz., moong and turmeric inter-planted with five year poplar are presented in Table 2. The Photosynthetic Active Radiation (PAR) was highest during afternoon irrespective of type of under-storey crops with an average of 494.42 µmolm^{-2}s^{-1} and 412.54 µmolm^{-2}s^{-1} for moong and turmeric, respectively. Physiological behaviour of crops under control conditions were also investigated and it was found that the PAR remain almost in the same range with the maximum of 1103.35 µmolm^{-2}s^{-1} and minimum of 1100.2 µmolm^{-2}s^{-1}. The least PAR was recorded during evening (4 pm) with 123.11 µmolm^{-2}s^{-1} and 96.25 µmolm^{-2}s^{-1} for moong and turmeric, respectively, whereas, in open condition, maximum and minimum PAR during evening hours was 575.39 µmolm^{-2}s^{-1} and 435.67 µmolm^{-2}s^{-1}, respectively. The photosynthesis rate 21.54 µmolm^{-2}s^{-1} was highest during morning hours in moong under control condition, but its value remained maximum during noon for turmeric (5.85 µmolm^{-2}s^{-1}) and moong (12.12 µmolm^{-2}s^{-1}) under tree canopy and under control condition its value was highest (9.78 µmolm^{-2}s^{-1}) for turmeric. The lowest rate of photosynthesis was recorded during evening for both open as well as shad conditions with minimum value of 2.02 µmolm^{-2}s^{-1} and 7.24 µmolm^{-2}s^{-1} in turmeric and moong, respectively.

The variations in temperature and relative humidity under four and five year old poplar plantations for the period of April to September, 2009 are presented in Fig. 2. The difference between open and shade condition for both parameters increased with increase in canopy age and modification in micro-climate became more pronounced. These changes in the micro-climatic conditions influenced the physiological process in the under-storey crops, thus affecting the crop yield. Under canopy, PAR availability varies with the tree species and this in-turn affects the under-storey crop growth and productivity[16], which was recorded in the present study as well.

Table 2. Diurnal variation in eco-physiological parameters of crops grown under poplar trees canopy and open condition during 2009

Time	PAR (µmol photonsm^{-2}s^{-1})	Transpiration rate (mmolm^{-2}s^{-1}) (E)	Stomatal conductivity (mmolm^{-2}s^{-1}) (C)	T air °C	T leaf °C	Photosynthesis rate (µmolm^{-2}s^{-1}) (Pn)	Internal CO_2 (ppm) (Ci)
Moong under poplar canopy							
9:00 AM	338.61	2.65	299.84	34.1	34.6	8.82	345.32
12 Noon	494.42	3.31	243.54	35.56	36.23	12.12	349.23
4:00 PM	123.11	2.07	167.44	35.45	36.15	7.24	465.33
Moong in open							
9:00 AM	611.43	5.94	435.28	36.8	38.43	21.54	229.02
12 Noon	1100.2	6.45	351.43	41.04	42.48	17.23	311.21
4:00 PM	435.67	5.37	155.36	39.68	39.65	15.67	361.26
Turmeric under poplar canopy							
9:00 AM	202.3	0.63	95.85	32.68	34.32	2.78	229.08
12 Noon	412.54	1.77	164.88	32.96	34.4	5.85	348.14
4:00 PM	96.25	0.85	93.94	23.34	24.18	2.02	455.14
Turmeric in open							
9:00 AM	743.12	1.03	137.29	35.65	39.13	4.24	255.24
12 Noon	1103.35	3.45	211.75	38.12	39.82	9.78	286.34
4:00 PM	575.39	1.31	35.46	36.84	37.39	2.56	363.13

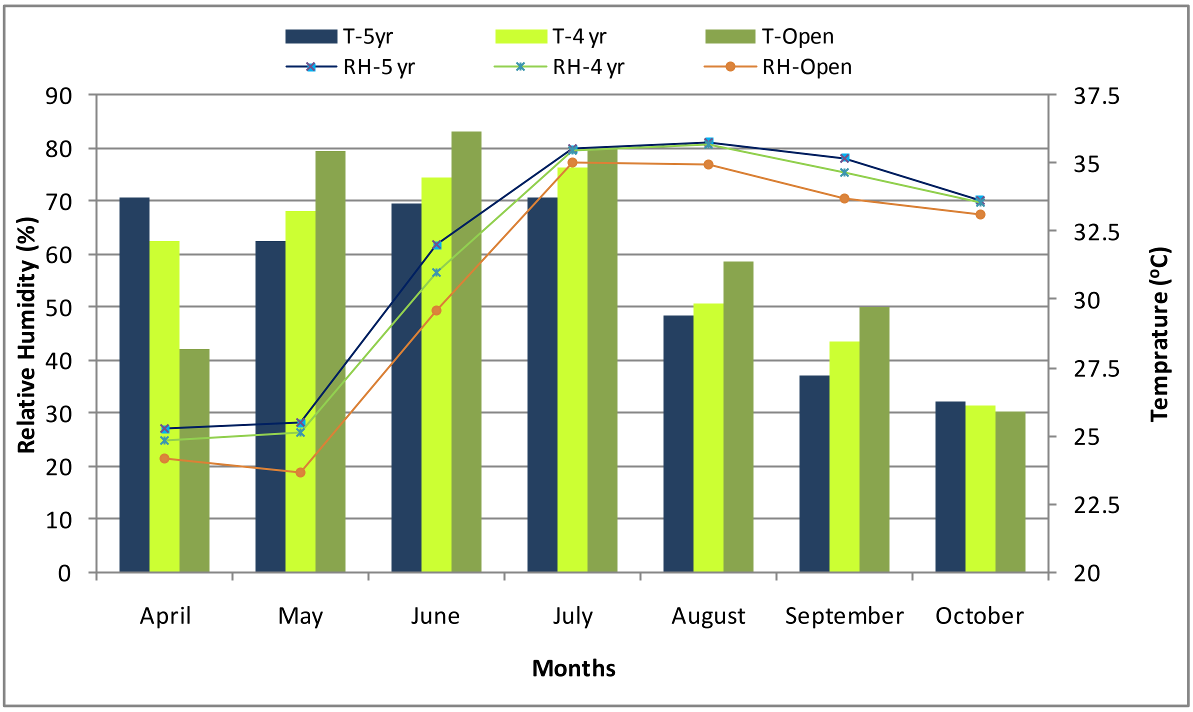

Figure 2. Micro-climatic modification under poplar tree canopy

3.3. Yield Parameters of Turmeric and Moong Crops

It is evident from Fig. 3 that rhizome weight of turmeric was found more in open conditions than under shade. The rhizome weight was more under three year old canopy than four year. The rhizome thickness and length also showed the same trend. The per cent yield reduction in turmeric was more under five year than in the four year old poplar canopy. An earlier study revealed that fresh rhizome yield of turmeric (*Curcuma longa* L.) decreased significantly as the age of poplar increases[19]. The study indicated that turmeric can be grown in poplar plantation up to three years though the yield decreases in the third year, which is in lines with earlier observations[20], however quality is least affected under shade[21]. The reduction of 35.25 and 48.36 per cent was observed under three and four year old tree canopy (Fig.3). Whereas, in case of moong crop, it had less vegetative growth under the four year old than the three year old poplar canopy and in open. Number of pods per plant, pod weight and seed weight per plant reduced almost to half in four year old plantation as compared to control (Fig. 3). Yield reduction was 57.91 per cent and 36.87 per cent in five and four years old plantations, respectively. Similar results have also been reported for temperate agro-forestry systems. For example, maize and soybean yields were reduced to 73 per cent and 79 per cent of the sole crop yield, respectively, when grown in alley-cropping configurations involving poplar and silver maple in Canada[22]. In the present study, the tree reduced crop yield as the canopy advanced in age. Radiation is an important factor affecting crop photosynthesis, development and yield. Shade imposes a limitation on growth and development of crop plants but varies with shade tolerance of crops. To avoid these possible yield losses, canopies of trees should be pruned to reduce shading and also root-pruned to reduce possible competition for water, nutrients and light and increase crop yield in agroforestry systems[23,24]. PAR under canopy is crucial in vegetative as well as reproductive growth. Higher reduction in yield in moong in comparison to turmeric indicates suitability of rhizomatous crops under shade than seed/grain crops. The root crops respond well to the changed micro-climate under tree canopy i.e., soil/air temperature, relative humidity, light (quality/quantity), etc. Comparatively higher yield reduction in soybean than turmeric has also been recorded earlier[25], exhibiting better suitability of turmeric under tree canopy. Therefore, it is essential to promote light conditions under canopy through managing geometry of plantations or exerting judicious pruning and identification of suitable crops and their specific varieties under prevailing light conditions because when photon flux density decreases to approximately 40 per cent, the carbon assimilation becomes light limited[26]. The specific responses are also dependent on the arable crops[27].

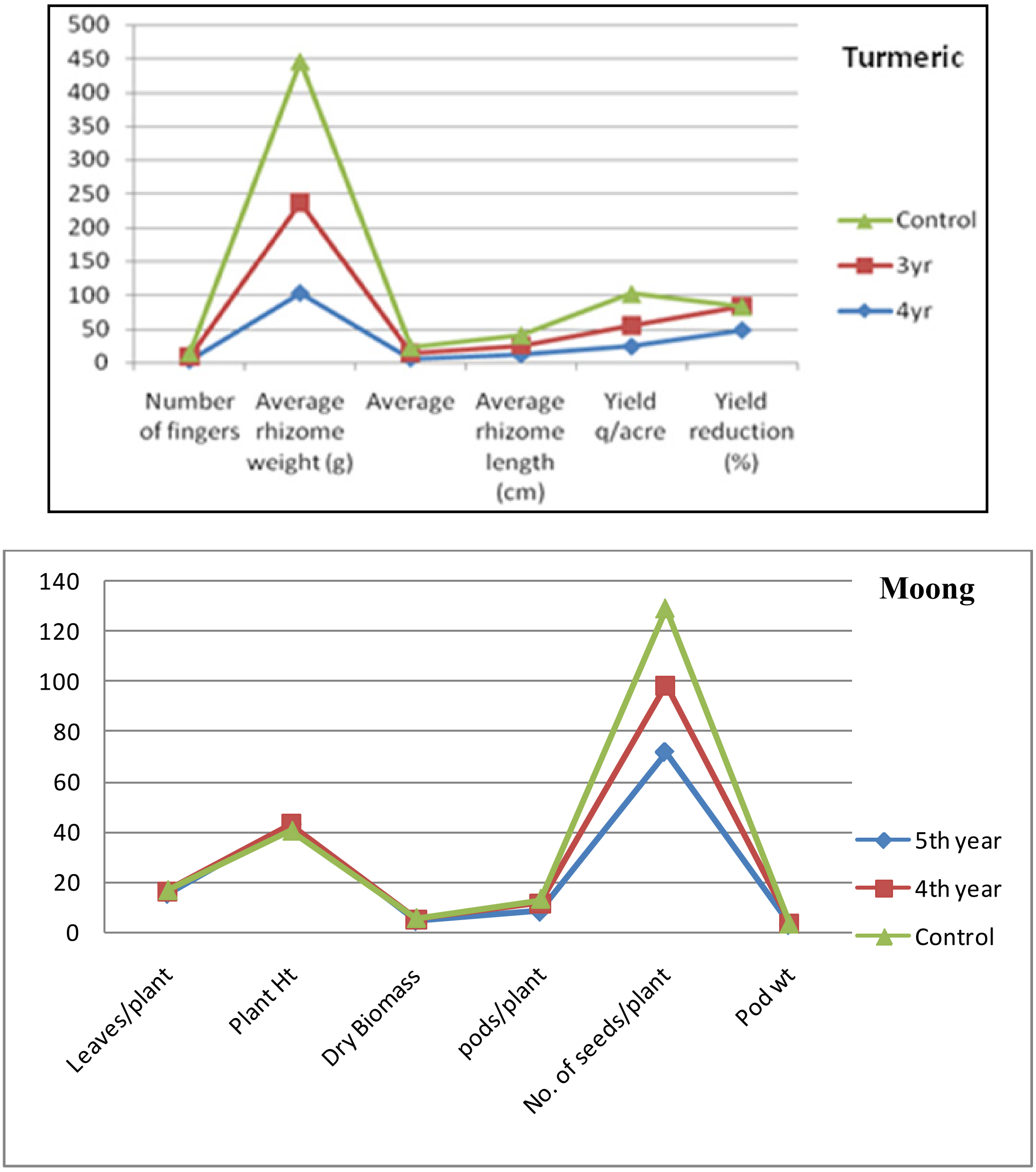

Figure 3. Yield and yield contributing parameters of turmeric and moong under agri-horti-silvicultural system

3.4. Economic Analysis

Productivity cannot be criteria for the making comparison in different farming systems. Farmers itself will adopt the system on its economic sustainability. Therefore, an economic analysis was made to assess balance sheet so that the economically viable farming system is adopted. The income from moong crop followed by garlic/onion (spice crops) + fruit crops (still not in commercial bearing) and poplar timber had maximum income (US$ 5725) followed by turmeric + fruits and poplar (US$ 4814), which was much higher than to traditional rice-wheat rotation (Table 2). However, it is interesting that still farmers prefer to raise rice-wheat crops, because of assured government purchase, whereas, the rates of other crops keep fluctuating and they have to compete in the market. Governments are stressing hard to make farmers aware of the negative ecological and economic impacts of rice-wheat rotation and the results obtained in the present study will certainly help in convincing the farmers to adopt new rotations. Turmeric though is less affected under shade but the additional income from onion/garlic in moong based system makes the rotation more remunerative. The success storey of agroforestry in general has already been accepted by the Ministry of Environment and Forests, Government of India to achieve the targets of 33 per cent tree cover and farmers in specific for economic sustainability. Poplar alone makes a big difference in profitability in the system[8,28] but our conscious efforts in selecting appropriate crop/variety and management of components will actually decide the sustainability and adoption of the system. The reduced yield of the crops under the tree canopy, lowers down the annual profitability margin than sole crop cultivation but the overall profitability of the intercropping system after tree harvesting is substantially high than traditional crop cultivation[5,29], thus encourages the framers to invest in this sector and consider it a best performing low risk asset in near future.

Table 2. Comparative income of different crop rotations on per hectare basis in UD dollars

Rotation	Income ha^{-1} (USD)
Rice-wheat	1897
Turmeric + fruit crops + poplar	4814
Moong + Garlic/onion* + fruit crops + poplar	5725

* Garlic/onion follows moong crop during winter season, however, not discussed in the paper but included for economic analysis. Turmeric is annual crop, whereas moong is season crop. Rice-wheat rotation is traditionally followed but needs diversification.

4. Conclusions

The crop yield is certainly affected by the shade of the trees in tree-crop combinations but the resources use efficiency is better under trees than in open conditions. However, on system basis the productivity of the combination is more than pure cropping. Additionally, the multiple outputs can be realized by the small farmers with limited land holdings. The distribution of benefits and costs are important for the farmers to evaluate the intercropping options. A system may be technically feasible for a biologist/ecologist but may be irrelevant for the farmers. It is largely the economics, which determines whether tree-crop interventions are an opportunity or burden. The multiple cropping (agri-horti-silvicultural system) has been found economically feasible {two to three times higher income (USD 4814-5725) than traditional rice-wheat rotation (USD 1897)} and many progressive farmers have adopted the same. The selection of intercropping components however must be based on the principle of minimizing the competition and maximizing complimentarily among themselves. Adequate care and proper management are essential to harness appropriate productivity in the intercropping systems. The continuity in research, regulated market and defined policy including framing of “Agroforestry Policy” will be favourable in motivating the farmers to adopt agroforestry for higher productivity and livelihood security. In the changing climate scenario, tree-crop interface may be an adoption strategy and the carbon market may add to the profitability margins, which are yet not realized.

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