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Effect of multipurpose trees on growth and yield of ginger (*Zingibar officinale* Roscoe.) and turmeric (*Curcuma longa* L.) grown as intercrops in Arunachal Pradesh of North East India

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ABSTRACT

One of the most commonly adopted strategies for addressing environmental degradation in rural areas of the tropics is agroforestry. In *jhum* and degraded land, plantation of fast growing multipurpose tree species play major role not only in rehabilitation of degraded lands but also increase the net productivity of these lands with proper crop tree combination. Keeping this in view, performance of two rhizomatous crops *i.e.*, turmeric (*Curcuma longa*) and ginger (*Zingibar officinale*) was evaluated under rainfed conditions as sole crops and with 15-year old well established stands of forest tree species located at the research farm of ICAR Research Complex for NEH Region, Research Centre, Basar, Arunachal Pradesh. The average illumination below the canopies varied from 72.0 to 79.2% of incident radiation on turmeric and 71.7 to 78.8% of incident radiation on ginger. Turmeric and ginger were cultivated in the inter row spaces of 24 and 12 Multipurpose trees (MPTs), respectively. Turmeric and ginger did not perform well under as many as 18 and 5 MPTs, respectively. Turmeric, in association with nitrogen fixing tree species *Alnus nepalensis* and *Parkia roxburghii* did not significantly reduce its productivity. Leaf area and leaf area index (LAI) was significantly higher under *A. nepalensis* than the sole turmeric crop. However, MPTs had significantly negative effect on the growth and yield attributes of ginger crop. The reduction in yield of ginger ranged from 11.3 to 31.3%. It may be inferred that turmeric cultivation was more profitable than the ginger and both the crops showed highest benefit:cost ratio *i.e.*, 3.10 and 2.36, respectively under *A. nepalensis* based agroforestry systems in comparison to the other MPT based agroforestry systems.

1. INTRODUCTION

North eastern hill region of India is a unique ecosystem in the Indian subcontinent which is very rich in natural resources and has wide edaphic, topographic and climatic variability along with high biological diversity. In this region, slash and burn agriculture, called shifting cultivation or *jhum kheti*, is a widely adopted crop production practice in vast areas. In Arunachal Pradesh, around 80.50% area is under forest (ISFR, 2011). Farmers do not grow any crop in between but they cut down the forest to create space for *jhum kheti*. In these lands, farmers hardly go for cropping after third year as the crop yield significantly reduces. They leave their land fallow to rehabilitate by the regeneration of forest vegetation. It takes nearly 8 to 10 years for the *Jhum* lands to regain its capacity

to support crop production. Plantation of fast growing and economic tree species shall play major role in restoration soil physical, chemical and biological health of the degraded *jhum* lands. In this context, multipurpose trees based agri-silvicultural system has immense potential to utilize and conserve rainfed areas for betterment of resource-poor farmers (Das *et al.*, 2011). Care should be taken in selection of tree species as some of the tree species having sparse foliage allow filtered light and permit intercropping even after the trees are fully grown. Growing of one additional intercrop under the tree species will not only generate extra yield and income, but also would help to check soil erosion through ground coverage and improve the soil physico-chemical condition (Ghosh and Pal, 2010). In the tree based farming, a number of interactions within

the systems arise that may be neutral, beneficial, or potentially detrimental. To maximize the potential benefits of tree-based intercropping systems, competitive interactions need to be avoided in order to properly design and manage intercropping systems (Thevathasan *et al.*, 2004; Nair, 1993). Therefore, choice of the tree species and its companion crop at a given age of the tree stand is most important for the success of an agroforestry system. In the NE hills, some finest quality ginger and turmeric are cultivated which are usually planted in furrow with subsequent ridging on slopping land. Cultivation of such crops in agroforestry systems with appropriate tree species combination holds promise in arresting land degradation. The present study was therefore undertaken to evaluate ginger and turmeric as intercrops with various tree species which are extensively planted in the sub Himalayan region. The ultimate objective is to find the best tree-crop combination for higher yield and economic benefits.

2. MATERIALS AND METHODS

The experiment was conducted during 2010 and 2011 at the research farm of ICAR Research Complex for NEH Region, Arunachal Pradesh Centre, Basar, West Siang District of Arunachal Pradesh, India located in the Eastern Himalayan region of India (27°95' N latitude, 94°76' E longitude and 660 m above msl). The site experiences humid climate with mean annual rainfall of 2230 mm; most of the rainfall is received from south-west monsoon. The rains start in the month of April and continue up to October; June and July are the wettest months. Average number of rainy days in a year is about 144 days. The mean monthly maximum temperature varies from 16.9°C (January) to 28.8°C (August). The mean monthly minimum temperature varies from 6.8°C (January) to 21.2°C (August). The soil was sandy loam in texture and acidic in reaction having pH value less than 4.5.

Turmeric was planted under the canopy of 24 tree species (*Aleurites montana*, *Alnus nepalensis*, *Altingia excelsa*, *Bombax ceiba*, *Cinnamomum camphora*, *Cryptomeria japonica*, *Cunninghamia lanceolata*, *Dubanga grandiflora*, *Emblia officinalis*, *Grevillea robusta*, *Ixonanthes khasiana*, *Livistona jenkinsiana*, *Machilus bombycina*, *Manglietia insignis*, *Mesua ferrea*, *Michelia obtusifolia*, *Morus laevigata*, *Parkia roxburghii*, *Phoebe goalparensis*, *Pinus kesiya*, *Pinus wallichiana*, *Symingtonia populnea*, *Syzygium cumini* and *Terminalia myriocarpa*) and ginger was cultivated under 12 tree species (*Aleurites montana*, *Alnus nepalensis*, *Cinnamomum camphora*, *Cunninghamia lanceolata*, *Dubanga grandiflora*, *Grevilia robusta*, *Hevea brasiliensis*, *Manglietia insignis*, *Mesua ferrea*, *Michelia obtusifolia*, *Parkia roxburghii* and *Terminalia myriocarpa*). Among these species, only seven best performing tree species viz. *Alnus nepalensis*, *Terminalia myriocarpa*, *Parkia roxburghii*, *Manglietia insignis*, *Hevea brasiliensis*,

Dubanga grandiflora and *Grevillea robusta* were selected for further analysis. Turmeric and ginger were also planted as sole crop without any association with tree species for comparison. The experiment was laid out in a randomized complete block design with three replications. Both the crops were sown in the second week of April during 2010 and 2011 at the spacing of 60x20 cm. The row to row distance was 3 m. The decomposed leaves (organic matter) were used as source of nutrients for crop production.

Growth and Yield Attributes

Five randomly selected turmeric and ginger plants were tagged in each sample plot. All the growth parameters were recorded from the tagged plants. In the end of December, samples for yield determination were collected from sample plots of 1.2x1.2 m size after discarding the border rows.

Leaf Area Estimation

Leaf length and breadth of turmeric were measured with the help of measuring scale. Leaf area was computed by multiplying the product of leaf length and width with a conversion factor 0.72 as suggested by Rao and Swamy (1984). For the ginger, the regression equation developed by Ancy and Jayachandran (1994) was used for leaf area estimation:

$$LA = 0.6695LW - 0.7608$$

Where, LA is leaf area, L and W are leaf length and leaf breadth, respectively.

Solar Radiation Interception

Solar radiation interception was recorded with the help of Digital Lux Meter (TES 1332- TES Electrical Electronic Corporation) at 1.00 p.m. during clear sunny days on top canopy of turmeric and ginger and the incident radiation were compared with sole crop.

Soil Moisture

Soil moisture content was determined gravimetrically at four depths i.e., 15, 30, 45 and 60 cm for all sample locations on 13th August. No intervening rain occurred between August 10 and August 15.

Statistical Analysis

Univariate analysis was performed on different growth and yield attributes of ginger and turmeric, soil moisture and solar radiation. SAS 9.2 programme was used for analyses of the data. The statistical significance of difference between means were computed by least square difference at 5% level of significance.

3. RESULTS AND DISCUSSION

Growth and Yield of Intercrops under MPTs

Turmeric

Growth parameters of turmeric such as leaf length, leaf breadth, leaf area and LAI were significantly higher under

A. nepalensis as compared to sole turmeric crop (Table 1). Except *D. grandiflora* and *G. robusta*, none of the MPTs had any significant negative effect on yield of turmeric (Table 2). Although statistically not significant, highest yield was obtained with *A. nepalensis* (19.73 t ha⁻¹) followed by *T. myriocarpa* (18.43 t ha⁻¹), *P. roxburghii* (18.43 t ha⁻¹) and *M. insignis* (17.57 t ha⁻¹). Similar was the trend with number and weight of primary and secondary rhizomes. There was variation in light penetration through the over storey tree canopies. In turmeric, highest transmitted light (illumination) was observed under *M. insignis* (79.2%) followed by *D. grandiflora* (79.1%) and *P. roxburghii* (78.3%) which were statistically at par with each other (Table 1). *T. Myriocarpa* (72.0%) allowed least light penetration through the tree canopy. Although light transmission was less under *A. nepalensis*, *P. roxburghii* and *T. myriocarpa*, the yield was better than the other tree species. Rhizome yield of turmeric with *A. nepalensis* (1.26 t ha⁻¹) was more than the sole crop grown on open. Partial shade may be one of the factors that might have influenced the growth of turmeric (Sundararaj and Thulasidas, 1976). Photomorphogenic responses are induced by photoreceptors such as phytochromes, cryptochromes and phototropins as a response to the incident solar radiation. These responses influence the pattern of investment of captured resources that can be different for different plant species and their associates. Turmeric might have higher solar energy conversion efficiency under shade than under

open condition. Higher LAI of turmeric under the tree canopy could be the reason for higher energy conversion efficiency as LAI is strongly correlated with net assimilated rate and crop growth rate. This is considered as the response of the photosynthetic apparatus to an increased demand for assimilates caused by rapid bulking of rhizomes. Turmeric is reported to have been successfully grown in association with many forest trees providing both substantial growth and income as compared with non-shaded condition (Pradhan et al., 2003; Bisht et al., 2004). In similar agroclimatic and soil conditions at Pottangi in the Odisha state of India, the plant height, number of tillers plant⁻¹, number of leaves tiller⁻¹ of turmeric under the canopy of guava (*Psidium guajava*), mango (*Mangifera indica*), coffee (*Coffea arabica*) and rose apple (*Syzygium jambos*) were significantly higher than the sole turmeric (Mohanty et al., 1998). Dhyani and Chauhan (1989) also reported that turmeric in Meghalaya performed better under partial shade. In poplar based agroforestry systems turmeric performed better under partial shade (Jaswal et al., 1993). Apart from light illumination and incident solar radiation, soil moisture, soil organic matter and fertility of the soil might have influenced the growth and yield of turmeric. The dynamics and bio-availability of major plant nutrients improve with soil organic matter (Sanchez and Logan, 1992). Many studies reported increase in growth of turmeric when organics in the form of FYM, oil cakes and green leaves were applied. In agroforestry systems, there is

Table: 1
Effect of tree species on the growth components of turmeric (Average of two years)

Tree species	Plant height (cm)	Number of leaves/plant	Leaf length (cm)	Leaf breadth (cm)	Leaf area (cm ² plant ⁻¹)	Leaf area Index	Solar radiation transmission (%)
<i>Alnus nepalensis</i>	88.0 ^d	12.0 ^d	48.9 ^a	14.3 ^a	6105.0 ^a	3.39 ^a	74.8 ^{bcd}
<i>Terminalia myriocarpa</i>	82.1 ^b	11.0 ^{bc}	45.8 ^{ab}	13.3 ^{abc}	4890.5 ^{ab}	2.72 ^{ab}	72.0 ^d
<i>Parkia roxburghii</i>	82.1 ^b	10.3 ^{cd}	44.3 ^{abc}	13.5 ^{ab}	4457.8 ^{bc}	2.48 ^{bc}	78.3 ^{bc}
<i>Manglietia insignis</i>	79.3 ^{bc}	9.4 ^{de}	42.2 ^{abc}	13.1 ^{abc}	3757.6 ^{bcd}	2.09 ^{bcd}	79.2 ^b
<i>Hevea brasiliensis</i>	78.6 ^{bc}	8.0 ^f	40.8 ^{bc}	12.4 ^{bcd}	2937.6 ^d	1.63 ^{de}	76.2 ^{bcd}
<i>Dubanga grandiflora</i>	74.3 ^d	8.6 ^{ef}	40.4 ^{bc}	12.1 ^{de}	3051.1 ^{cd}	1.70 ^{cde}	79.1 ^b
<i>Grevillea robusta</i>	71.0 ^d	8.1 ^f	37.0 ^c	11.6 ^d	2508.6 ^d	1.39 ^e	74.3 ^{cd}
Sole turmeric	83.4 ^b	11.3 ^b	38.8 ^{bc}	12.7 ^{bcd}	4019.5 ^{bcd}	2.23 ^{bcd}	100 ^a
LSD (p=0.05)	5.70	0.90	7.30	1.22	1442.4	0.80	4.81

Means followed by the same alphabet are statistically at par at 5% level of significance

Table: 2
Effect of tree species on the yield of turmeric (Average of two years)

Tree species	Mother Rhizome		Primary Rhizome		Secondary Rhizome		Yield (g plant ⁻¹)	Yield (t ha ⁻¹)
	Number	Weight (g)	Number	Weight (g)	Number	Weight (g)		
<i>Alnus nepalensis</i>	2.8 ^a	82.9 ^a	8.4 ^{ab}	94.6 ^a	14.5 ^a	177.9 ^a	357.1 ^a	19.7 ^{3a}
<i>Terminalia myriocarpa</i>	2.4 ^{abc}	78.6 ^{ab}	7.9 ^{bc}	86.8 ^{abc}	13.3 ^b	174.2 ^{ab}	335.9 ^{ab}	18.43 ^{ab}
<i>Parkia roxburghii</i>	2.4 ^{abc}	77.6 ^{ab}	7.9 ^{bc}	86.0 ^{abcd}	13.2 ^{bc}	173.5 ^{ab}	346.5 ^{ab}	18.43 ^{ab}
<i>Manglietia insignis</i>	2.3 ^{bc}	76.7 ^{abc}	7.3 ^{cd}	84.0 ^{bcd}	12.1 ^{cd}	170.2 ^{ab}	326.7 ^{abc}	17.57 ^{abc}
<i>Hevea brasiliensis</i>	2.2 ^{bc}	73.4 ^{bc}	7.1 ^{de}	81.3 ^{cd}	11.8 ^d	165.4 ^{abc}	312.6 ^{bcd}	16.30 ^{bcd}
<i>Dubanga grandiflora</i>	2.1 ^c	72.5 ^{bc}	6.8 ^{de}	80.9 ^{cd}	11.0 ^{de}	162.6 ^{bc}	283.9 ^d	15.50 ^{cd}
<i>Grevillea robusta</i>	2.0 ^c	69.6 ^c	6.5 ^e	77.0 ^d	10.3 ^e	154.2 ^c	289.9 ^{cd}	14.17 ^d
Sole turmeric	2.6 ^{ab}	79.3 ^{ab}	8.7 ^a	92.7 ^{ab}	14.1 ^{ab}	167.7 ^{abc}	333.0 ^{ab}	18.47 ^{ab}
LSD (p=0.05)	0.45	7.41	0.63	9.20	1.15	14.37	40.89	2.56

Means followed by the same alphabet are statistically at par at 5% level of significance

better nutrient cycling because of addition of leaf litter, twigs and other above ground biomass and turnover of roots below the ground. Annual input of nutrients to forest floor via litter falls of *A. nepalensis* could be 183 to 235 kg nitrogen, 4.9 to 7.0 kg phosphorus and 33.5 to 39.5 kg potassium ha⁻¹. Total accretion of nitrogen through biological nitrogen fixation was reported to range between 29 to 117 kg ha⁻¹ (Sharma, 1993).

Ginger

The growth and yield of ginger as an intercrop was quite opposite to turmeric. Effect of most of the tree species on the growth and yield of ginger was antagonistic in nature (Table 3 and Table 4). Yield reduction in ginger under different MPTs varied from 11.3 to 31.3% over sole ginger crop. Among all the tree species, *G. robusta* had the most negative effect on the growth parameters of ginger. Plant height, number of tillers plant⁻¹, leaf breadth, leaf area and leaf area index were lowest under *G. Robusta* and were significantly lower than those in sole ginger crop grown in open conditions (Table 3). There was no significant difference between plant height and leaf breadth of ginger under *A. nepalensis* and sole ginger. But this tree species had significantly positive effect on the number of leaves per tiller, leaf length, leaf area and leaf area index as compared to the sole crop of ginger. Number of tillers plant⁻¹ was highest in sole ginger which was significantly higher than that of the ginger grown under the tree species. In case of

yield, highest rhizome yield was obtained in sole ginger (18.67 t ha⁻¹) which was significantly higher than *A. nepalensis* (16.57 t ha⁻¹), *T. myriocarpa* (15.93 t ha⁻¹) and *P. roxburghii* (15.43 t ha⁻¹) (Table 4). The yield reduction due to these three tree species was 11.3%, 14.68% and 17.35%, respectively. Highest yield reduction was attributed to *G. robusta* (31.3%). In contrast to our results, ginger is known to be shade loving species producing better quality produce and higher rhizome in many parts of the world including India. Both turmeric and ginger grow well under the shade of 25% beyond which performance of the crop reduces significantly (Jaswal *et al.*, 1993; Thevathasan *et al.*, 2004). In the Arunachal Pradesh of North East, even 25% shade by the multipurpose tree species significantly reduced yield of ginger to a tune of nearly 2.1 t ha⁻¹. Probably the radiation received in this part of the country is lower than the critical level of sunshine required for the optimum growth of ginger. During rainy season, the crop might not have received sufficient light below the tree canopy as most of the times the days remain cloudy. Average sunshine hours in this part of India is around 3 hrs per day during the month of June and July and part of August. Therefore, sole ginger performed better than the intercrop. Performance of ginger under *A. nepalensis* was statistically at par with *P. roxburghi* and *T. myriocarpa* but was higher than *H. brasiliensis*, *D. grandiflora* and *G. robusta*. This might be due to higher nutrient availability resulting from biological nitrogen fixation by *A. nepalensis*

Table: 3
Effect of tree species on the growth and yield attributes of ginger (Average of two years)

Tree species	Plant height (cm)	Number of tillers plant ⁻¹	No of leaves tiller ⁻¹	Leaf length (cm)	Leaf breadth (cm)	Leaf area (cm ² plant ⁻¹)	Leaf area Index	Solar radiation transmission (%)
<i>Alnus nepalensis</i>	72.6 ^a	10.0 ^b	15.1 ^a	24.5 ^a	3.2 ^a	7935.6 ^a	4.41 ^a	74.2 ^{bcd}
<i>Terminalia myriocarpa</i>	66.7 ^b	9.3 ^{bc}	14.4 ^{ab}	23.4 ^{ab}	3.1 ^{ab}	6406.0 ^{ab}	3.56 ^{ab}	71.7 ^d
<i>Parkia roxburghii</i>	64.6 ^b	9.0 ^{cd}	14.0 ^{abc}	22.3 ^{abc}	3.0 ^{abc}	5590.7 ^{bc}	3.11 ^{bc}	77.1 ^{bc}
<i>Manglietia insignis</i>	62.7 ^{bc}	8.3 ^d	13.7 ^{abc}	21.2 ^{bc}	2.8 ^{bc}	4433.4 ^{cd}	2.46 ^{cd}	78.8 ^b
<i>Hevea brasiliensis</i>	58.8 ^{cd}	8.1 ^d	13.1 ^{bcd}	20.3 ^c	2.7 ^c	3846.0 ^d	2.14 ^d	75.7 ^{bcd}
<i>Dubanga grandiflora</i>	54.8 ^{de}	7.1 ^e	12.7 ^{cd}	19.9 ^c	2.7 ^c	3244.2 ^{de}	1.80 ^{de}	77.8 ^b
<i>Grevillea robusta</i>	52.4 ^e	6.5 ^e	11.8 ^d	19.4 ^c	2.2 ^d	2133.2 ^e	1.19 ^e	72.9 ^{cd}
Sole Ginger	77.1 ^a	11.3 ^a	12.6 ^{cd}	21.3 ^{bc}	2.9 ^{abc}	5840.6 ^{bc}	3.24 ^{bc}	100 ^a
LSD (p=0.05)	5.50	0.95	1.61	3.08	0.38	1633.2	0.91	4.78

Means followed by the same alphabet are statistically at par at 5% level of significance

Table: 4
Effect of tree species on the yield of ginger (Average of two years)

Tree species	Mother Rhizome		Primary Rhizome		Secondary Rhizome		Yield (g plant ⁻¹)	Yield (t ha ⁻¹)
	Number	Weight (g)	Number	Weight (g)	Number	Weight (g)		
<i>Alnus nepalensis</i>	1.7 ^{ab}	42.6 ^b	6.0 ^b	72.7 ^b	10.4 ^b	112.0 ^{ab}	219.3 ^b	16.57 ^b
<i>Terminalia myriocarpa</i>	1.7 ^{ab}	41.1 ^b	5.7 ^{bc}	70.8 ^b	9.6 ^{bc}	102.1 ^{bc}	205.9 ^{bc}	15.93 ^{bc}
<i>Parkia roxburghii</i>	1.6 ^{bc}	38.2 ^{bc}	5.2 ^{cd}	67.7 ^{bc}	9.2 ^{bcd}	95.2 ^{cd}	197.3 ^{bc}	15.43 ^{bc}
<i>Manglietia insignis</i>	1.5 ^{bcd}	35.2 ^c	4.8 ^d	62.4 ^{cd}	8.7 ^{cd}	88.8 ^{cd}	192.7 ^{bc}	14.77 ^{cd}
<i>Hevea brasiliensis</i>	1.4 ^{cd}	33.3 ^{cd}	4.1 ^e	58.6 ^d	8.0 ^{de}	89.3 ^{cd}	182.0 ^c	13.83 ^{de}
<i>Dubanga grandiflora</i>	1.4 ^{cd}	30.2 ^{de}	3.7 ^e	56.2 ^{de}	7.3 ^{ef}	82.5 ^d	177.7 ^c	13.30 ^e
<i>Grevillea robusta</i>	1.3 ^d	28.1 ^e	3.0 ^f	51.5 ^e	6.2 ^f	80.8 ^d	171.3 ^c	12.83 ^e
Sole Ginger	1.9 ^a	52.8 ^a	7.2 ^a	82.6 ^a	12.1 ^a	126.7 ^a	264.7 ^a	18.67 ^a
LSD (p=0.05)	0.23	4.94	0.57	6.72	1.38	16.28	36.18	1.44

Means followed by the same alphabet are statistically at par at 5% level of significance

and high above ground and below ground contribution of biomass to the soil. However, 24.1% lower yield of turmeric and 31.3% of ginger were recorded with *G. robusta* which might be due to reduced light penetration and/or presence of growth inhibiting factors associated with the tree species as in certain tree crop combinations, the trees may secrete some allelopathic chemicals and/or adversely affect availability of soil water, available light for crop photosynthesis, and available nutrients for use by the adjoining field crops (Jaswal *et al.*, 1993).

Soil Moisture

In the MPT-turmeric land uses, some degree of variation was observed in moisture content at different soil depths and between different tree species. Moisture contents under sole ginger and turmeric were generally lower than those under the MPTs. This was more pronounced in the top 15 cm soil depth (Table 5). Up to 15 cm soil depth, it was highest under *A. Nepalensis* (25.8%) which was significantly higher than *D. grandifolia* (23.5%), *G. robusta* (23.2%) and *P. roxburghii* (23.0%). In case of ginger, variation in moisture content under different MPTs was less as compared to turmeric. Up to 15 cm depth, difference between sole ginger and MPT based land uses was significant ($p < 0.05$). But, there was no significant difference in soil moisture content among the different MPTs across all the depths. Saha *et al.* (2007) reported

better moisture regime under trees vegetation like *A. nepalensis*, *P. roxburghii*, *etc.* as compared to the open. The above ground biomass also acts as a mulch material that helps to conserve moisture. This is reflected in our experiment where moisture content under the trees is higher than that of the open fields.

Economic Returns from the Rhizomatous Crops

Net return and B:C ratio of the rhizomatous crops grown in association with different tree species and as sole crop varied significantly (Table 6). As the yield varied under different tree species, it directly influenced the returns per unit area. The cost of production was highest in sole crops as it involved two additional weedings. In turmeric, highest net return was obtained from landuse associated with *A. nepalensis* followed by *T. myriocarpa* and least was obtained from *G. robusta*. The B:C ratio followed the similar trend. In ginger, net return was highest in sole ginger crop which was statistically at par with *A. nepalensis* although rhizome yield was more in sole ginger than the ginger growth in association with *Alnus nepalensis*. Among the net returns from ginger as intercrop with the MPTs, highest profit was earned from ginger cultivated under *A. nepalensis* followed by *T. myriocarpa*. However, least return was recorded on *G. robusta*. B:C ratio was recorded highest on *A. nepalensis* followed by *T. myriocarpa*.

Table: 5
Soil moisture content at various soil depths under different MPTs

MPTs based sytems	Soil moisture under Turmeric (%)				Soil moisture under Ginger (%)			
	15 cm	30 cm	45 cm	60 cm	15 cm	30 cm	45 cm	60 cm
<i>Alnus nepalensis</i>	25.8 ^a	29.7 ^{ab}	33.3 ^a	36.6 ^{ab}	23.5 ^a	26.5 ^a	30.6 ^{ab}	33.4 ^a
<i>Terminalia myriocarpa</i>	25.7 ^{ab}	30.2 ^a	34.2 ^a	38.7 ^a	24.4 ^a	27.5 ^a	31.0 ^a	33.7 ^a
<i>Parkia roxburghii</i>	23.0 ^{cd}	27.4 ^{bc}	33.0 ^a	37.4 ^{ab}	22.4 ^{ab}	26.5 ^a	29.6 ^{ab}	32.5 ^{ab}
<i>Manglietia insignis</i>	24.5 ^{abc}	29.5 ^{ab}	34.3 ^a	39.3 ^a	23.1 ^a	27.2 ^a	29.3 ^{ab}	31.8 ^{ab}
<i>Hevea brasiliensis</i>	24.5 ^{abc}	30.2 ^a	35.3 ^a	39.4 ^a	23.6 ^a	27.3 ^a	30.5 ^{ab}	32.4 ^{ab}
<i>Dubanga grandiflora</i>	23.5 ^{bc}	29.5 ^{ab}	34.6 ^a	38.5 ^a	23.1 ^a	25.8 ^a	30.6 ^{ab}	32.2 ^{ab}
<i>Grevillea robusta</i>	23.2 ^{cd}	29.6 ^{ab}	33.2 ^a	37.1 ^{ab}	23.6 ^a	26.5 ^a	30.8 ^{ab}	32.5 ^{ab}
Sole turmeric/ginger	21.2 ^d	25.1 ^c	29.8 ^b	34.7 ^b	20.7 ^b	25.0 ^a	27.8 ^b	30.8 ^b
LSD (p=0.05)	2.22	2.74	2.78	2.84	2.10	NS	3.01	1.96

Means followed by the same alphabet are statistically at par at 5% level of significance

Table: 6
Economic returns from Ginger and Turmeric (Average of two years) in the agroforestry system

Tree species	Turmeric			Ginger		
	Cost of Cultivation* (₹ 10 ³)	Net return (₹10 ³)	B:C	Cost of cultivation (₹ 10 ³)	Net return (₹10 ³)	B:C
<i>Alnus nepalensis</i>	48	149 ^a	3.10 ^a	40	94.4 ^a	2.36 ^a
<i>Terminalia myriocarpa</i>	48	140 ^b	2.92 ^{ab}	40	87.2 ^b	2.18 ^b
<i>Parkia roxburghii</i>	48	135 ^{bc}	2.81 ^{bc}	40	82.4 ^{bc}	2.06 ^{bc}
<i>Manglietia insignis</i>	48	130 ^{cd}	2.71 ^c	40	77.6 ^c	1.94 ^c
<i>Hevea brasiliensis</i>	48	117 ^e	2.44 ^d	40	71.2 ^d	1.78 ^d
<i>Dubanga grandiflora</i>	48	110 ^f	2.29 ^{de}	40	65.6 ^e	1.64 ^e
<i>Grevillea robusta</i>	48	93 ^g	1.94 ^f	40	62.4 ^e	1.56 ^e
Sole turmeric/ginger	58	125 ^d	2.16 ^c	53	95 ^a	1.79 ^d
LSD (p=0.05)		6.00	0.19		5.48	0.12

Means followed by the same alphabet are statistically at par at 5% level of significance.

*includes cost expended for seeds, fertilizer, human labour, pesticides; unit sale price of turmeric ₹ 10 kg⁻¹ and ginger ₹ 8 kg⁻¹.

Economic profitability takes into account the cost of production and the net return per rupee of investment. However, it largely depends on the yield harvested with the expenditure incurred to generate that yield. A properly designed and managed tree-based intercropping system can create a dynamic agro-ecosystem resulting in increased and diversified farm income (Dyack *et al.*, 1999). *A. nepalensis* gave higher net return followed by *T. myriocarpa*. The higher net return under the MPT based agroforestry systems was primarily due to reduction in cost of cultivation. If the returns from the tree component is ascertained and economic value is assigned, the net benefit and the benefit cost ratio will increase further. Among ginger and turmeric, the risk associated with turmeric is less because turmeric is less perishable than ginger. Secondly, turmeric can be converted into powder and stored which can act as an insurance against the price fluctuations in the market.

4. CONCLUSIONS

Turmeric performed better than ginger under seven selected MPTs in Arunachal Pradesh. Partial shade had positive influence on the yield and yield attributes of turmeric. Economic return from the turmeric crop was more under the MPTs than the sole crop. *Alnus nepalensis*, a frankia mediated nitrogen fixing tree species, had positive effects on some of the growth attributes like leaf length, width, leaf area and the LAI of turmeric. However, yield of ginger reduced significantly and there was a yield reduction of 2.1 t ha⁻¹ to 5.84 t ha⁻¹ due to the MPTs. Among the MPTs, better growth and yield attributes were recorded under *A. nepalensis*. Although the yield of ginger was less under *A. nepalensis* than the sole crop, the B:C ratio was more for *A. nepalensis*.

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