Intercropping for Climate Resilient Agriculture in North Eastern Hill Region of India

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Authors are hopeful that the publication will be helpful to the various stakeholders for improving productivity, resource use efficiency and increasing resilience in crop production to changing climatic conditions

Authors

Content

Cropping Systems of NEH Region

The agricultural practice in the north eastern hill (NEH) region are broadly of two distinct type viz., settled farming practiced in the plains, valley/foot hills and terraced slopes and shifting cultivation in the hill slopes. Depending upon the system of farming, food habits and climatic conditions, several crops are grown in the region. Among cereals, rice is the most predominant and staple food crops and accounts for about 64.9% of net cropped area. Maize and small millets are next important crops covering about 10.5 and 2.5% of net cultivated area, respectively. Earlier mono-cropping with low yielding varieties of rice and maize was the common practices in NE region. Now double and triple cropping systems have been developed under rainfed condition for upland and wet land area to some extent.

In NEH region, rice – fallow is the predominant cropping system under low land as well as upland situation excluding Sikkim where maize is the predominant crop of uplands. The most efficient cropping systems identified for different area in the region are potato-rice, rice-rice, maize-ragi, maize-mustard, maize-sunflower, maize + French bean-mustard. The groundnut being a recent introduction in the North East region, has proved potential and can be a good substitute of uneconomical upland rice and maize or it can be grown as intercrop with rice and maize for higher productivity and economic return (Panwar et al., 2003). Munda et al. (1999) reported that maize (green cob) –groundnut –mustard was the most profitable cropping system in mid altitude of Meghalaya followed by French bean (Green pod)-French bean (Grain). Ginger and turmeric are the two important commercial spice crop of Meghalaya. Experimental results revealed that for upland area rice-Toria, Maize- Groundnut and Maize -Toria, are promising cropping systems under rainfed condition. In the low land, cropping systems like rice- French bean, rice–tomato/potato, rice-carrot etc. are promising when cultivated under raised and sunken bed system of cultivation. Under irrigated condition it is even possible to achieve even 300% cropping intensity eg. Maize-French bean-carrot, Maize- French bean-potato etc. Traditionally farmers' practices mixed cropping without following any definite row arrangement for subsistence.

Scope of intercropping

Growing of crops in mixtures is an age old practice in the NEH region of India. Shifting cultivation popularly known as *jhumming* is predominantly practiced in upland where major food crops like upland rice and maize are grown with various crop mixtures. This is the common feature of the hill farming in the north eastern hill region of India, particularly in Meghalaya. However, systematic intercropping of legumes such as soybean, groundnut, black gram, French bean etc. with the main crop was found highly promising to maximize the productivity of upland and to reduce the risk of crop failure, instability of crop production, better utilization of farm resources and to maintain soil fertility and ultimately the additional income to the farmer. Intercropping/mixed cropping also provides some amount of food and nutritional security to the farmers' family. Intercropping also ensures regular income from the field. When a short duration crop is intercropped in a long duration crop, the short duration crop matures early and provides intermediate income to the family. Besides higher productivity and income, it also ensures higher employment opportunities for the farmers.

What is intercropping?

Intercropping is growing of two or more crops simultaneously on the same piece of land with a definite row pattern. For example, growing rice + soybean in 4:2 row ratio i.e. after every 4 rows of rice, 2 rows of soybean is sown. Thus, cropping intensity in space dimension is achieved. Intercropping is also defined as the agricultural practice of cultivating two or more crops in the same space at the same time (Andrews and Kassam, 1976). A practice often associated with sustainable agriculture and organic farming, intercropping is one form of polyculture, using companion planting principles Intercropping may benefit crop yield or help in control of some kind of pest, or may have other agronomic benefits.

The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop. Careful planning is required, taking into account the soil, climate, crops, and varieties. It is particularly important not to have crops competing with each other for physical space, nutrients, water and sunlight. Lodging-prone plants may get structural support by their companion crop (Trenbath, 1976). Delicate or light sensitive plants may be given shade or protection, or otherwise wasted space can be utilized. For example multi-tier system where coconut occupies the upper tier, banana the middle tier, and pineapple, ginger, or leguminous fodder, medicinal or aromatic plants occupy the lowest tier.

Intercropping of compatible plants also encourages biodiversity, by providing a habitat for a variety of insects and soil organisms that would not be present in a single crop environment. This biodiversity can in turn help to limit outbreaks of crop pests (Altieri 1994) by increasing the diversity or abundance of natural enemies, such as spiders or parasitic wasps. Increasing the complexity of the crop environment through intercropping also limits the places where pests can find optimal foraging or reproductive conditions.

Types of intercropping system

Based on the percent of plant population maintained for each crop in intercropping system, it is divided in two types-

1. **Additive series**: In this system, the main crop is sown with 100 percent of its recommended population in pure stand which is known as the base crop. Another crop known as intercrop (component crop) is introduced into the base crop by adjusting or changing crop geometry. The population of intercrop is less than its recommended population in the pure stand. For example, growing of soybean/groundnut between two rows of maize crop in1:1 row ratio (Fig 1a).

Fig 1a. Intercropping in additive series

2. **Replacement series:** In this system of intercropping, both the crops are called component crops. By sacrificing certain proportion of population of one component, another component is introduced. For example, growing of maize + soybean in 2:2 row ratio (Fig 1b).

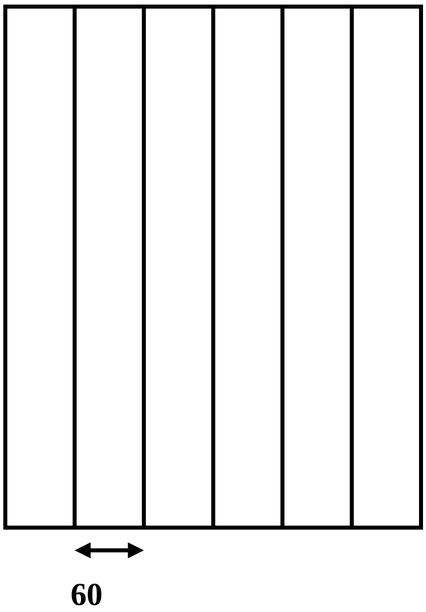
Fig 1b. Intercropping in replacement series

Various crop geometry for intercropping in maize has been presented as schematic diagrams (Fig 2). Paired row planting is an arrangement where two rows are paired by reducing the interspace so that the space between another two rows are increased. The intercrops are accommodated in that increased row area (Fig 2d).

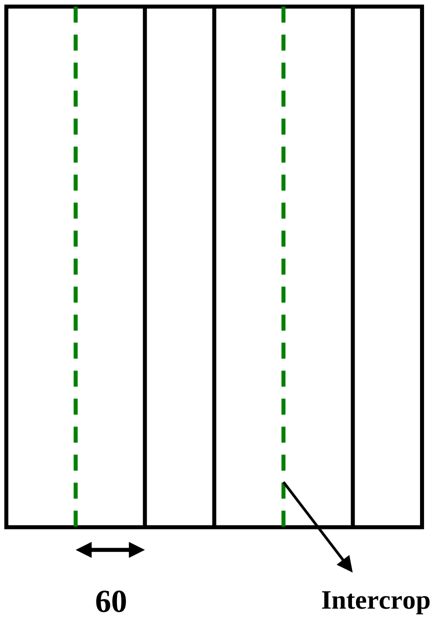
- In NEH Region of India, replacement series performs better compared to additive series

Objectives of Intercropping/Mixed cropping

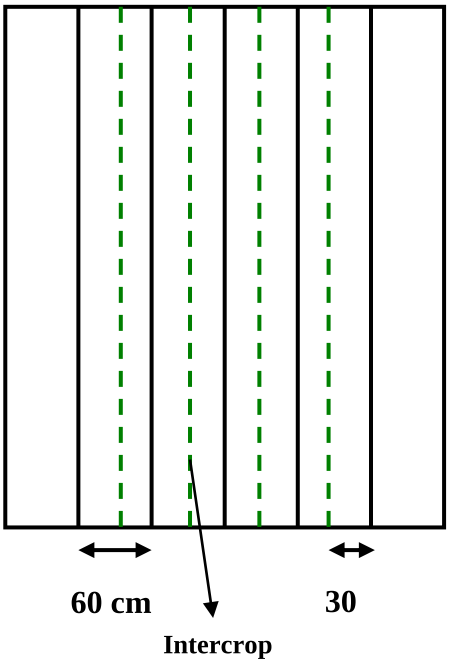
- Insurance against total crop failure under aberrant weather conditions under rainfed conditions or disease and pest epidemics.
- Increase in total productivity and income per unit land area in addition to stability in production.
- Efficient utilization of resources such as land, labour and inputs.
- Efficient pest and disease management. Crop competition is utilized to suppress weeds.
- Soil and water conservation, soil fertility buildup and farm diversification



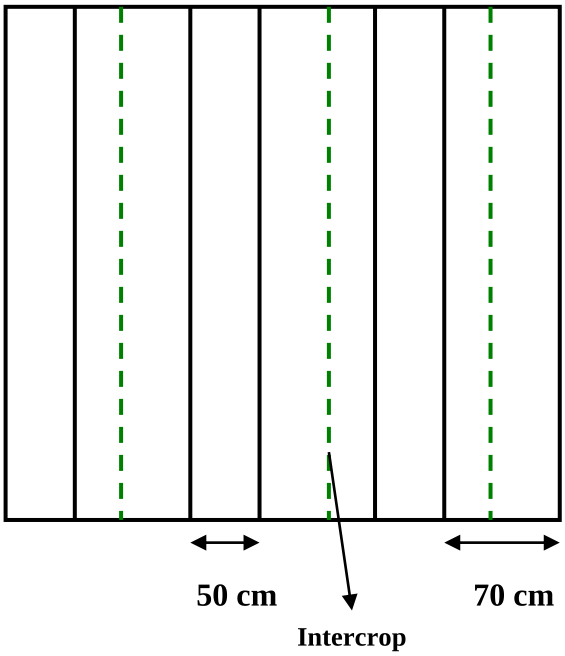
a. Sole crop



b. Replacement series (2:1)



c. Additive series



d. Paired row planting

Fig 2. Schematic diagram showing various geometry for intercropping in maize

Principles of intercropping

There are certain important requirements which should be kept in mind for successful intercropping-

- As for as possible, there should be minimum competition between the main crop and intercrops for resources like water, nutrients and light.
- When two crops are to be grown together, they are chosen in such a way that there is variation in their growth duration. The peak periods of growth of the two crop species should not coincide and the time of peak nutrient demands of component crops should not overlap. In such arrangements, a quick maturing crop completes its life cycle before the other crop starts. This can be achieved either by genetic difference in crop species or manipulation of planting dates. Normally short and long duration crops are grown together. Food crops are usually mixed with cash crops to ensure both sustenance and cash income.
- Competition for light should be less among the component crops.
- Complementarities should exist between the component crops.
- Combine crop species as per local need and other site specific agro-climatic factors.

Interactions between different component crops

When crops are grown in association, there is interaction between different component crops. This interaction may be competitive or non-competitive or complementary. Plants require growth factors such as solar radiation, water, nutrients, and carbon dioxide for their growth. In intercropping, different kinds of plants compete with one another for the limited growth factors. When crops are grown in sequence, residual effect of the preceding crop influences the succeeding crop. This may be helpful or harmful. For example, ginger cultivation is practiced every year in new field to avoid the effect of toxic chemicals (Allelopathic chemicals) left in the soil which affects the growth and development of succeeding crop. In contrast, roots of leguminous crops and their residues add nitrogen to the soil.

Some of the indigenous intercropping systems practiced by the farmers of Meghalaya are intercropping of maize in potato field (maize is grown at a spacing of about 1m x 0.75m in potato) and Maize + French bean (3a & 3b). Some cucurbits and gourds are grown in between maize and potato fields.

Fig 3a. Maize intercropped in potato in farmer's field

Fig 3b. Maize + French bean intercropping in farmer's field

Factors affecting the performance of intercropping systems/competition

1. **Solar radiation:** The taller crop in the intercropping systems intercepts most of the solar radiation while shorter component suffers. In some intercropping systems solar radiation is utilized efficiently by both the crops. For example, in rice + soybean (4:2) intercropping systems both the component crops are short stature which results less competition for light between both the crops.

2. **Water and nutrients:** In additive series of intercropping both the crops (Base and Component crop) compete each other for water and nutrients whereas replacement series avoids such type of competitions. The component crops may be one of the following types -
   - Combination of low N and P requiring component crop (legume) and low P and high N requiring component crop (cereal)
   - Component crops having similar input requirement

3. **Maturity of the crop**
   - Same maturity period- the component crop matures at the same time
   - Different maturity period- the component crop matures at different time

4. **Growth rate**
   - Component crops having slow initial growth and fast initial growth
   - Component crops having moderate initial growth and fast initial growth
   - Combination of fast initial growth of component crops
5. **Different root system**
   - Combination of deep root and shallow root component crops
   - Combination of deep and deep root component crops
   - Combination of shallow and shallow root component crops

6. **Allelopathic effect**
   - Inhibitory effect on component crops
   - Stimulatory effect on component crops

7. **Planting pattern**
   - Additive series
   - Replacement series

Complementary effects of intercropping

Complementary interaction between component crops both in time and space in an intercropping system is called annidation. The canopies of component crops may occupy different vertical layers with taller component tolerant to strong light and shorter component favouring shade. Similarly root system of component crops may occupy different soil layers and exploit nutrients and resources more efficiently. When two crops of wider duration are planted in an intercropping system, their peak nutrients demands are likely to occur at different periods. After the harvest of early maturing crop, the

Fig 4. Maize + soybean (2:2) intercropping system

situation becomes more favourable for late maturing crops. Eg. Maize + green gram, pigeon pea + amranthus etc, where green gram and amaranthus are harvested in about 60 days and maize and pigeonpea in 120-130 days.

In an intercropping system, involving a legume and a non- legume crop, part of the nitrogen fixed in the root nodule of the legume may become available to non- legume component crop (Fig 4). The presence of rhizospheric microflora and mycorrhiza on one species may lead to mobilization and greater availability of nutrients not only to the species concerned, but also to the associated species. Another example is the provision of physical support by one species to the other in intercropping system. Erect crop plants may improve the yield of a climber as in the case of coconut + pepper, beetle nut + pepper, maize + French bean etc.

Intercropping with legumes: way to climate change adaptation

Agricultural production will have to increase to satisfy expected demands for food and feed for the fast growing world's population. Climate change will make this task more difficult due to its adverse impacts on crop production. Intercropping is an efficient strategy that can be followed with desirable outcome in the changing climatic scenarios. The important determining factors for intercropping are the differentiating development, growth pattern, and stature and rooting behavior so that this supplement each other instead of going after the resources and make preparations for climate difficulties (Zhang et al., 2011). Intercropping with legumes provides many benefits such as stable yields, efficient use of resources, fix atmospheric N in soil, improve soil quality, reduce crop yield variability and fortify family diets with protein and micronutrients (Layek et al., 2018). With increased leaf cover in the intercropping system, transpiration makes the microclimate cooler, which helps to reduce the soil temperature and associated evaporation (Miao et al. 2016). The intercropping system also explored the soil more efficiently as against growing of the single crop (Hinsinger et al., 2011). It is highly significant when moisture content in soil is limited as a higher amount of available water is being used in intercropping as against sole cropping. Having deep root system, legumes can extract moisture and nutrients from deeper layer and hence does not compete with associated cereals (Das et al., 2016). Apart from fixing N in soil, a part of fixed N is also spared for the cereal intercropped and hence, enhance crop growth even in the N deficient soil (Layek et al., 2015). Intercropping also reduces the chance of total crop failure and assured income from some crops in the event of extreme weather events. Intercropping also reduces soil, water and nutrient loss due to effective ground cover, hedge formation and obstruction to runoff during heavy showers. Thus, intercropping is a sustainable adaptation to climate change especially to extreme weather events like drought, floods etc.

Important intercropping systems of NEH Region

Intercropping in cereals

Intercropping systems involving cereal and legume crops are common in India. The intercropped legume, besides increasing the total productivity of the system, also plays an important role in economizing the resource use especially fertilizer N. Farmers in the North Esat like those in Jaintia Hills, Ribhoi District etc grows pulses like French bean with the maize, where maize supports the French bean as climber.

Maize/rice + soybean are a predominant intercropping system (Fig 5a &5b) in the North eastern hill region of the country, where rainfall ranges from 700 to 2000 mm spreading over 6-7 months. Groundnut is also a good compatible companion crop with maize/rice (6a). Farmers in Meghalaya, grows French bean as intercrop in maize where maize acts as staking/supporting material for French bean (Fig 7).

Fig 5a. Rice + soybean (4:2) intercropping

Fig 5b. Rice + groundnut (4:2) intercropping

Upland rice which is low yielding due to severe soil moisture stress, weed competition, damage of crop by birds etc. should be grown along with an intercrop. Upland rice can be intercropped with soybean, French bean, groundnut or black gram/ green gram in 4:2 row ratios for enhancing the total system productivity per unit land area (Table 1 & 2).

Table 1. Average yield (t/ha) of main crop/intercrop and Rice Equivalent Yield in intercropping system under mid hills of Meghalaya

Main crop/Intercrop	Rice yield	Intercrop yield	LER	Rice Equivalent Yield
Upland Rice	2.03	-	-	2.03
Upland Rice + French bean (4:2)	1.30	3.53	1.22	6.0
Upland Rice + Groundnut (4:2)	1.51	0.80	1.28	3.51
Upland Rice + Soybean (4:2)	1.74	0.75	1.48	3.24

Sole crop yield of French bean 6.06 t/ha, groundnut 1. 5 t/ha, Soybean 1.2 t/ha.

Fig 6a. Maize + Groundnut (2:1) intercropping

Fig 6b. Maize + soybean (2:2) intercropping

- To avoid excessive vegetative growth of soybean in maize + soybean (2.2) intercropping systems, detopping of soybean was done to prevent lodging of soybean crop as sown in Fig. 8.
- The pruned biomass of component crop (soybean) can be used as green leaf manure or mulch (Table 3).
- Lodging results drastic reductions in yield and produce quality of component crops

Table 2. Average yield (t/ha) of main crop/ intercrop and Maize Equivalent Yield in intercropping system under mid hills of Meghalaya

Main crop/Intercrop	Main crop yield	Intercrop yield	LER	Maize Equivalent Yield
Maize	4.75	-	-	4.75
Maize + Groundnut (2:2)	3.65	1.15	1.42	7.00
Maize + Soybean (2:2)	3.68	1.05	1.46	6.83

Sole crop yield of groundnut 1.76 t/ha, Soybean 1.52 t/ha.

Fig 7. Maize + French bean intercropping in Jaintia Hills, Meghalaya

Fig 8. De-topping in soybean for green manuring

Table 3. Effect of de-topping of soybean on nutrient recycling and yield of rice and maize.

Cropping system	Fresh wt (t/ha)	Dry wt (kg/ha)	Nutrient content (%)			Nutrient recycled (kg/ha)			Yield of rice/maize/soybean (t/ha)
			N	P	K	N	P	K	
Rice sole crop	-	-	-	-	-	-	-	-	3.2.0
Maize sole crop	-	-	-	-	-	-	-		3.9.0
Rice + soybean	2.44	292.8	2.69	0.164	1.49	7.87	0.48	4.36	2.61 +0.85
Maize + soybean	2.18	261.6	3.50	0.253	1.59	9.16	0.66	4.16	3.67+ 0.73

- In rice + soybean intercropping, yield of rice without detopping = 2.40 t/ha
- In maize +soybean intercropping, yield of maize without detopping = 3.30 t/ha

Intercropping with legumes has a positive impact on symbiosis for nitrogen fixation and increasing soil fertility. The infertile land requires more nitrogen for proper plant growth and better yield and thus the demand for soil nitrogen in Himalayan rainfed agriculture is increasing day-by-day. Unique characteristics like high protein content (2-3 times more than cereals), nitrogen fixing ability, soil ameliorative properties and ability to thrive better under unfavorable conditions make pulses an integral component of agriculture in Himalaya. When non-leguminous crops like, maize and millets are with legumes, they provide support for climbing to the later, minimizes disease and weed problems and alleviates the negative impacts of continuous cereal cultivation on soil fertility. Five years study on a sloping land (35% slope) in eastern Himalayas (1000 m ASL) revealed that the average maize equivalent yield (MEY) was the highest for rice-lentil system (16.2 t/ha) followed by maize-French bean (14.6 t/ha) and maize-rapeseed system (9.01 t/ha) while the lowest MEY was recorded in monocropped farmers' practice (3.08 t/ha). Soil Organic Carbon (SOC) stock in the fifth year of study at 0-30 cm was much higher under maize - French bean system (61.4 t/ha) compared to monocropped Maize (55.4 t/ha). Land equivalent ratio (LER) indicates the area which will be required to produce the same productivity as that of an intercropping system. Intercropping of pulses with cereals like maize are reported to give LER of 1.22 to as high as 1.75 in different locations of IHR (Table 4).

Table 4. Land equivalent ratio (LER) as affected by intercropping

System	LER	Location	Reference
Maize + soybean (2:2)	1.41	North-West Himalayas	Pandey et al (1999)
Maize + green gram (1:1)	1.54	West Bengal	Patra et al (1999)
Maize + grain legume	1.22 - 1.54	Uttarakhand	Khola et al (1999)
Maize + field pea (1:1)	1.51	Uttarakhand	Devi (2014)
Maize + field pea (2:2)	1.60	Uttarakhand	Devi (2014)
Maize + cowpea (1:2)	1.63	Eastern Himalaya	Choudhary et al. (2014)
Maize + French bean (1:2)	1.75	Eastern Himalaya	Choudhary et al. (2014)
Maize + black gram (1:2)	1.66	Eastern Himalaya	Choudhary et al. (2014)

Intercropping in pulses

For pigeonpea, short duration grain legumes such as black gram and soybean are the best companion crops. Groundnut is also a suitable intercrop in pigeonpea. Sorghum is commonly intercropped with pigeonpea. Short duration vegetables like coriander, amaranthus etc can also be intercropped in pigeon pea. For first 45 days the growth of pigeonpea remains slow which can be effectively utilized for growing an intercrop.

Intercropping in horticultural crops

Traditionally farmers of NEH grow ginger, turmeric etc. in citrus plantations. However, it is not recommended as ginger and turmeric are exhaustive in nature. As far as possible less competitive crops like pulses (green gram, black gram, rice bean etc) should be grown as intercrop. These crops not only give additional income but also maintains soil fertility and reduces soil erosion. Cultivation of beetalvine in the under -storey of arecanut is also a common practice at low altitudes in the North Eastern Region.

Intercropping in Agroforestry

Crops like ginger, turmeric, root crops etc are grown as intercrop under pine forests in Meghalaya. Experimental results revealed that crops like groundnut and fodder grasses like congo-signal can also be grown successfully as intercrops in pine forest. In Sikkim, large cardamom is grown as intercrop in Alder plantations.

Intercropping on raised beds in lowlands

Raised and sunken bed technology has been standardized for crop intensification in lowlands (Das et al., 2014). Cultivation of vegetables on raised beds in lowlands have been reported to enhance system productivity and income substantially over rice monocropping. Cabbage + pea (43.29 t/ha), cauliflower + methi (22.36 t/ha) and broccoli + pea (17.85 t/ha) recorded the highest system productivity in mid-altitude of Meghalaya. These intercropping combinations gave cabbage, cauliflower and broccoli equivalent yields of 11.45, 4.83 and 6.07 t/ha, respectively (Table 5, 6 & 7).

Table 5. Effect of cabbage based intercropping system on system productivity on raised bed

Cropping system	Cabbage yield (t/ha)	Intercrop yield (t/ha)	Cabbage Equivalent Yield (t/ha)
Cabbage + Pea	31.85	3.27	11.45
Cabbage + Methi	34.26	1.54	7.70
Cabbage + Coriander	32.36	0.67	4.22
Cabbage + Radish	29.57	6.54	4.09
Cabbage + Carrot	31.01	5.56	9.73
Cabbage + Sole	36.54		

Table 6. Effect of cauliflower based intercropping system on system productivity on raised bed

Cropping system	Cauliflower yield (t/ha)	Intercrop yield (t/ha)	Cauliflower equivalent yield (t/ha)
Cauliflower + Pea	15.28	2.87	6.70
Cauliflower + Methi	17.53	1.45	4.83
Cauliflower + Coriander	17.11	0.54	2.27
Cauliflower + Radish	13.27	4.58	1.91
Cauliflower + Carrot	15.44	6.10	5.34
Cauliflower + Sole	18.53		

Table 7. Effect of broccoli based intercropping system on system productivity on raised bed

Cropping system	Broccoli yield (t/ha)	Intercrop yield (t/ha)	Broccoli equivalent yield (t/ha)
Broccoli + Pea	11.78	3.47	6.07
Broccoli + Methi	12.66	1.28	3.20
Broccoli + Radish	9.54	5.84	1.82
Broccoli + Mustard	9.07	1.45	3.26
Broccoli + Lentil	12.84	1.43	4.47
Broccoli + Carrot	12.03	5.28	4.62
Broccoli + Sole	14.54		

Assessment of yield advantage in intercropping systems

Since several crops are involved in intercropping systems, it is not logical to compare total yield of different crops in one system with the other. Several indices are developed to evaluate intercropping systems.

Assessment of competition

The nutritional relationships between intercrops can be evaluated using relative yield (RY), relative N yield (RNY), relative P yield (RPY) and relative K yield (RKY) as given below.

$$\text{Relative yield (RY)} = \frac{\text{Intercrop yield}}{\text{Sole crop yield}}$$

$$\text{Relative nitrogen yield (RNY)} = \frac{\text{N uptake by intercrop}}{\text{N uptake by sole crop}}$$

$$\text{Relative nitrogen yield (RNY)} = \frac{\text{P uptake by intercrop}}{\text{P uptake by sole crop}}$$

$$\text{Relative nitrogen yield (RNY)} = \frac{\text{K uptake by intercrop}}{\text{K uptake by sole crop}}$$

i. If RY ≥ RNY, N is a limiting factor in intercropping performance
ii. If RY< RNY, N is not a limiting factor in intercropping performance
iii. Similar is the case for RPY and RKY.

Based on these indices, it is easy to identify the stage when a particular nutrient is deficient for one of the component crops or both (Ghosh *et al*. 2006).

Crop Equivalent Yields

The yields of different intercrops are converted into equivalent yield of any one crop based on price of the produce of the crop. The crop equivalent yield (CEY) is calculated as follows:

$$CEY = \sum_{i=1}^{n} (Yi \, . \, ei)$$

Where Yi is yield of i^{th} component and ei is equivalent factor of i^{th} component or price of i^{th} crop.

Example. Let the yields of rice and groundnut in a hectare of intercropping be 1,510 and 800 kg respectively. The total yield of intercropping system can be expressed as Rice Equivalent Yields (REY) by knowing the price of rice and groundnut. If the price of rice and groundnut are Rs. 6 and Rs. 15 per kg respectively:

$$\text{Equivalent Yield of rice} = \frac{1{,}510 \times 6}{6} = 1{,}510 \text{ kg i.e. the original yield.}$$

$$\text{Rice Equivalent Yield (REY) of groundnut} = \frac{800 \times 15}{6} = 2000 \text{ kg}$$

Equivalent Yield of system = 1,510 + 2,000 = 3,510 kg of rice

A rice equivalent yield of (REY) of groundnut 2000 kg means, the value of 800 kg groundnut is equivalent to 2000 kg rice.

Land Equivalent Ratio

Land equivalent ratio (LER) is the relative land area under sole crops that is required to produce the yields achieved in intercropping. LER can be mathematically represented as follows:

$$LER = \sum_{i=1}^{m} \frac{Yi}{Yij}$$

Where, Yi is the yield of i^{th} component from a unit area grown as intercrop and Yij is the yield of i^{th} component grown as sole crop over the same area. In brief, LER is the summation of ratios of yields of intercrop to the yield of sole crop.

Example. Let the yields of rice and groundnut grown as pure crops be 2500 and 2,000 kg/ha respectively. Let the yields of these crops when grown as intercrops be 1,810 and 1300 kg/ha respectively. The land equivalent ratio of rice + groundnut intercropping system is as follows:

$$\text{LER of rice} = \frac{\text{Yield of inter crop}}{\text{Yield of sole crop}} = \frac{1{,}810}{2{,}500} = 0.72$$

$$\text{LER of groundnut} = \frac{1300}{2000} = 0.65$$

LER of system = 0.72 + 0.65 = 1.37

LER of 1.37 indicates that 37 per cent yield advantage is obtained when grown as intercrops compared to growing as sole crop. It means sole crops have to be grown in 1.37 ha to get the same yield level that is obtained from 1.00 ha of intercropping. If the LER is less than 1, it means intercropping is not profitable compared to pure crop.

Aggressivity

Aggressivity (A) indicates the relative yield increase in crop "a" than crop "b" crop in an intercropping situation (McGilchrist, 1965). The aggressivity (A) of a cereal+ legume intercropping system can be derived from the following formula.

$$A_{cereal} = \{Yab / (Yaa \times Zab)\} - \{Yba / (Ybb \times Zba)\}$$
$$A_{legume} = \{Yba / (Ybb \times Zba)\} - \{Yab / (Yaa \times Zab)\}$$

Yab = Yield of cereal “a” in cereal+legume intercropping system
Yaa = Yield of cereal “a” in pure stand (sole cropping)
Zab = Sown proportion of cereal “a” in intercropping
Yba = Yield of legume “b” in cereal+legume intercropping system
Ybb = Yield of legume “b” in pure stand (sole cropping)
Zba = Sown proportion of legume “b” in intercropping

When the value of A becomes zero, none of the crops are considered as aggressive or both crops are equal in competition. If the value of A becomes positive, then cereal crop is considered as aggressive or dominant over intercropped legume. If the value of A becomes negative, then intercropped legumes are considered as aggressive or dominant over cereals.

Economic evaluation of intercropping systems

Land equivalent ratio (LER) and Relative yield total (RYT) etc. are the indices which gives the biological suitability of particular intercropping systems to an area. At the same time, cropping system should be economically viable and profitable. Several economic indices are available to evaluate the profitability of cropping systems.

Monetary advantage index (MAI)

$$MAI = \text{Value of combined intercrops} \times \frac{(LER-1)}{LER}$$

The higher the MAI value, more profitable is the cropping system.

Gross Return

The total monetary value of economic produce and byproducts obtained from the crops raised in the intercropping system is calculated based on prevailing local market price.

Cost of Cultivation

This is the total expenditure incurred for raising crops in a intercropping system.

Net Returns

Net return is obtained by subtracting cost of cultivation from gross return. It is a good indicator of suitability of an intercropping system since this represents the actual income to the farmer.

B**enefit: Cost Ratio**

This is the ratio of gross return to cost of cultivation, which can also be expressed as returns per rupee invested. Any value above 2.0 is considered safe as the farmer gets Rs. 2 for every rupee invested.

Management of intercropping systems

The crops in intercropping system are grown simultaneously. Therefore, management practices that are followed should aim to provide favourable environment to all the components, exploit favourable interactions among the component crops and minimize competition among the components.

Tips for management of intercropping systems

Seedbed preparation should be done as per the needs of base crop.

Component crops varieties should be less competing with the base crop and the peak nutrient demand period should be different from base crop.

Sowing practices should be slightly altered to accommodate intercrop in such a way that it causes less competition to base crop. For example, paired row planting or planting in fixed row ratio of intercrops. If the row to row spacing for pure crop of maze is 60cm, to accommodate a intercrop it can be altered as 50 cm between the paired rows and 70 cm between the two pairs of rows of maize and thereby laving sufficient space for a intercrop in between 70 cm row spacing (Fig 2b). By doing so, the maize population will be remained unchanged.

The intercrop may be sown along with the main crop or it may be altered as per the need of the crop.

Fertilizer dose should be applied more than the recommended dose for base crop. If the component crop is a legume, generally the fertilizer required for main crop is sufficient. The phosphorus dose may be increased by about 25 % to meet the requirement of intercrops.

The higher plant population used and early complete coverage of soil in intercropping system reduced weed infestation. For proper use of herbicides, the selectivity of herbicides to main as well intercrop should be taken into account to avoid any damage to either crops.

Crops in intercropping systems are less infested by pest and diseases.

Farmers' participatory trials in intercropping

In Meghalaya, farmers grow upland rice as the primary crop with intercrops of colocassia, chilli, cucumber, maize, and millet, among others in the *jhum* cultivation. To maximize upland productivity, reduce the risk of crop failure, preserve soil fertility, and better use of farm resources, the IRRI-IFAD project conducted a demonstration trial on intercropping a legume (soybean or groundnut) with upland rice in five locations in Ri-bhoi District, Meghalaya. The upland rice–legume intercrop had a ratio of 4:1. The improved varieties of upland rice (Bhalum1 and Bhalum2), soybean (JS-355), and groundnut (ICGS-76) were used in the trial. The yield and economic returns of demonstration trial were compared with those of a sole rice crop of a traditional variety. By intercropping soybean and groundnut with upland rice, farmers could generate and additional income of Rs. 22,300 and Rs. 27,550 per ha, respectively, compared to a sole crop of upland rice. The farmers responded positively to the rice-legume intercrop demonstration trial. Farmers reported that the intercrop improved their food security by substituting cheap vegetable-based protein for expensive animal-based protein. The farmers also pointed out two advantages of growing crops in rows: (1) this made it easier to use tools for weeding operations as opposed to traditional methods in which the intercrops are asymmetric or grown randomly, and (2) it lowered the labour requirement for weeding (Adhikari *et al.* 2008).

Fig 9. Participatory trials on farmers' field (Photo courtesy: d. v. d -Develop, validate and deliver News Letter, IFAD TAG 706.)

Alley cropping/Hedge row intercropping

It is a type of intercropping where arable crops are grown in between the alleys (interspace) formed by the two hedge rows or leguminous shrub rows. It is also called as hedge row intercropping. Depending upon the slopes, plant species involved, the alley width may vary from 2 to 5 m. In north east, legumionous sghrubs like *Crotolaria, Tephrossia, Casia, Acacia, Cajanus cajan, Flemingia Indigofera* etc are suitable as alley crop or hedge row crop. Ginger, turmeric, maize etc are grown in between the alley (Fig 10). The alley height is generally maintained at about 1 m by pruning periodically and the pruned biomass is either used as mulch or incorporated in to the soil as a source of nutrients. Intercropping in interspace of hedgerow is a proven and sustainable technology for the NEH Region. The hedgerow grown in the contours helps in developing natural terrace in few years time. This system of cultivation reduces erosion and conserves natural resources.

Fig 10. Maize grown in between *Tephrosia* hedge rows

Fig a. Turmeric + soybean intercropping

Fig b. French bean + soybean intercropping

Fig c. Ginger + soybean intercropping

Fig d. Incorporation of intercropped soybean biomass in ginger field.

Fig 11. Different combinations of intercropping in Agronomy Experiments, ICAR Research Complex, Umiam, Meghalaya

Fig 12. Black gram (Var. PD-4) intercropping with Guava in rainfed terrace under organic farming

Rice bean, black gram, soybean etc. can be intercropped with fruit crops for conserving/sustaining soil health and generating additional income. This also provides some resilience to farmers in case of harsh climate like drought etc.

Conclusions

Intercropping not only enhances productivity and system sustainability but also enhances farmers' income, employment and reduces risks against climatic aberrations and changes. When pulses, green manure and cover crops are intercropped with cereals, vegetables and fruits, it enhances the system sustainability by improving ecosystem services and conserving natural resources. Thus, intercropping should be promoted for advancing food, nutrition and environmental security especially in the harsh agro-climatic regions like north eastern hill region of India to provide sustainability in farming and as an adaptation strategy to changing climatic conditions.

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