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Bio-mulching for ginger crop management:Traditional ecological knowledge led adaptation under rainfed agroecosystems

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Sustainability of organic farming depends on the organic inputs. As such, other than a few fertilizers and plant protection measures, there have been scanty resources available to farmers for continuing organic farming. Some farmers in India have evolved traditional ecological knowledge (TEK) based location specific practices to sustain their agroecosystems and continue organic farming. In this paper, an attempt has been made to explore TEK-led adaptations in bio-mulching to grow ginger (*Zingiber officinale* Roscoe) as a crop and to test empirically the best practices including identifying the best leaves and local bio-mulching materials applied by farmers. The role of TEK-led adaptive practices for controlling moisture loss, temperature regulation, reduced disease incidence, quality yield and economic aspects of ginger production are examined. The study was conducted in nine randomly selected villages of Champawat district, Uttrakhand (Western Himalaya). Data was collected using open ended questions in association with participatory rural appraisal (PRA) tools. Results indicated that farmers have developed major TEK led adaptive practices for organic ginger production after seeding in the field, namely using the leaves of oak (*Quercus leucotrichophora* A. Camus.), *chir* pine needles (*Pinus roxburghii* Sarg.), local mixed grasses (e.g., *Chrysopogon fulvus* (Spreng.) Chiov, [*Cymbopogon distans* (Nees ex Steud.) W. Watson], [*Pennisetum glaucum* (L.) R.Br. syn. *Setaria glauca* (L.) P. Beauv], [*Heteropogon contortus* (L.) P.Beauv. ex Roem. & Schult]. shrubs [*Chromolaena odorata* (L.) R.M.King & H.Rob.] syn. *Eupatorium odoratum* L.) and animal wastage. This last consists of mixed oak, *bhimal* (*Grewia optiva* J.R. Drumm ex Burret), *kharik* (*Celtis australis* L.), *timala* (*Ficus auriculata* Lour.syn. *Ficus roxburghii* Stud.) leaves, grasses, paddy and finger millet straw and cow dung and urine. Women were observed to be using more of these TEK led adaptive practices than men. Empirical field studies carried out on TEK led adaptive practices under rain-fed agro ecosystems of farmers revealed significant results including longer rhizome length (up to 6.50 cm), higher number of rhizomes per plant (35.30), higher ginger yield (211.50 q/ha), higher B:C (benefit to cost) ratio (1:2.18) and lower percentage of disease (bacterial wilt; soft rot and leaf spot) incidence (17.5%) in oak leaf mulch. Soil moisture conservation (44.75%) and optimum soil temperature (24.80 ^{0}C) were recorded as significantly better under the oak leaves for using bio-mulching as compared to all other TEK led bio-mulching practices for organic ginger production. The oak leaves used as bio-mulch in organic ginger increased yield by 43% and net returns by 61% as compared to no mulching (control). It is concluded that, under temperate climate and rain-fed agro ecosystems, TEK led adaptive practices by farmers in growing ginger are economically feasible, energy efficient and ecologically sustainable, through the addition of soil organic carbon. However, there is need for scientific and institutional promotion in participatory modes for such practices, with a provision for integrating these practices with science and policy on climate adaptation.

Keywords: TEK led adaptations, Bio-mulching, Mid hills, Rain-fed, Agroecosystems, Ginger, Crop diseases, Resource farmers, Livelihood security

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Social ecological diversity in India has great potential to sustain natural resources and farming systems. Climatic variability, different levels of vulnerability in agriculture, and adaptive capacity of Indian farmers have been the major issues in sustainability research[1,2]. Despite considerable scientific and institutional support in crop production, there are still a number of location-specific traditional ecological knowledge (TEK) based adaptive practices in agriculture that have been developed and applied by resource-poor farmers in fragile ecosystems[2,3]. These farmers do not have economic capacity to purchase external inputs to sustain their agricultural production systems. Therefore ecological and economic necessity

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has promoted their own creativity and learning in sustaining their crops[4,5]. As well, fragile agro-ecosystems do not permit farmers to apply external inputs widely. Such human communities have some uncommon resources that can be used as an insight by the formal systems[6]. TEK-based adaptive practices help to cope with climate change and to sustain soil health and agricultural systems in general. Studies have shown that small and resource-poor farmers, through informal experimentation, creativity and adaptive management, are more capable than the growers of large size farms of maintaining crop diversity, energy efficient agriculture and agro-ecosystems[7,8].

As in other mountain states[9], ginger (*Zingiber officinale* Rosc.) has been an important horticultural cash crop for the farmers of Uttrakhand hills, bringing high returns. In the recent past, new cultivation practices were introduced and adopted by a large section of ginger growers in the region. However, some farmers have been continuing their location specific TEK-based adaptive practices to sustain ginger production.

In a mountain state like Uttarakhand, precautionary measures for ginger production such as selection of planting materials, field location, field preparation and elimination of some faulty cultural practices like removal of the mother rhizome from the ginger fields have been the most important approaches leading to higher production and productivity. Ginger in Uttarakhand commonly suffers from diseases such as soft rot (*Pythium aphanidermatum*), bacterial wilt (*Pseudomonas solanacearum*), leaf spot (*Phyllosticta zingiberi*) and storage rot caused by pathogenic, saprophytic fungi and bacteria[11]. There have been some efforts for controlling *Pythium aphanidermatum* through agronomic manipulation and application of farm yard manure (FYM). Soil and rhizomes treated by *Trichoderma viride* with neem (*Azadirachta indica* A.Juss.) dust into the soil were found to be effective organic solutions[12]. Due to abrupt changes in climate, farmers are facing increasing disease and insect pest outbreaks, especially since about the last 10-12 yrs. This problem becomes exacerbated when market prices of ginger are highly unstable[10].

Forest leaf bio-mulching in the organically grown ginger beds, using dry leaves, is a common adaptive practice among farmers of Uttarakhand under rainfed conditions. Some of the locally available forest trees (oak and *chir* pine) and local grasses [*Chrysopogon fulvus* (Spreng.) Chiov], [*Cymbopogon distans* (Nees ex Steud.) W.Watson], *Setaria glauca* L., *Heteropogon contortus* L., and shrubs (e.g., *Eupatorium odoratum* L.) possess anti-microbial properties[13] that help to maintain the health of crops. Bio-mulch leaf material with anti-microbial properties can reduce the problem of ginger diseases to some extent along with control of weeds and soil run-off. These adaptive practices that are in vogue among many farmers help to conserve and sustain soil moisture, minimize soil evaporation from higher solar radiation, optimize soil temperature, enhance seed germination, reduce soil erosion and control weeds[14]. Resource poor farmers who do not have the capacity to purchase external inputs have adapted such practices, and this is having a tremendous impact on soil and crop health, and playing a multiple role in natural resource conservation[2,15,16].

Little research has been done on TEK led bio-mulching and its effect on soil health and crop parameters in the Uttarakhand hill (western Himalaya, India) region. To remedy this gap, this study was carried out, with the following objectives: (1) to identify traditional adaptive practices on organic bio-mulching in vogue among ginger farmers; and (2) to study the best TEK-led bio-mulching adaptations for higher yield, net returns and low disease incidence in ginger crops in hill conditions of Uttarakhand state.

Our study also demonstrates the processes of preparation of such adaptive practices and other socio-cultural and gender dimensions, and provides scientific evidence of effects of TEK based adaptive practice in bio-mulching of ginger crops. We also delineate the role of TEK led adaptive practices in soil moisture conservation, maintaining soil temperature, controlling soil erosion, suppressing diseases in ginger and overall impacts on quantitative and qualitative parameters of ginger crop yields.

Research methodology

This study was conducted in Champawat district of Uttarakhand (29.33° N and 80.10° E; elevation 1400-1900 msl). This district has a temperate climate, and all the agro-ecosystems are rain-fed. The agricultural landscapes are undulating and highly fragile. Various social classes and of differing social power and economic status determine the adaptive capacity for local and external resources. The majority of local farmers are resource-poor, with small land holdings

(~0.20 ha). These farmers grow ginger, potatoes and finger millet crops, as well as rearing cows, goats and buffalo to diversify their farming systems and reduce environmental risks. In the recent past, climate change and its compounded effect with anthropogenic and other socioeconomic factors have resulted to increase these farmers' vulnerability.

The study was conducted during 2008-10 in the Champawat district of Uttarakhand. In the first phase, sampling of farmers was undertaken purposively, based on the existence of bio-mulching adaptive practices. In the second stage, three developmental blocks (Champawat, Lohaghat and Barakot) were selected randomly from the Champawat district. From each block, three villages, thus a total of nine, were sampled randomly: Sui, Raikot, Goom, Toli, Baproo, Gumodh, Bar-bora, Swala and Amori. From each village 6 farmers (3 male and 3 female), with a total of 54 farmers from the nine villages, were selected randomly. We undertook field testing of bio-mulch practices of 18 of these farmers (Table 1).

Data for exploring TEK led adaptive practices on bio-mulching was collected using open ended questions applied through an interview schedule. Farmers were interviewed both informally (during various meetings and project works) and formally in association with participatory rural appraisal (PRA) tools (transect walks, participant observations and agroecosystem analysis) to identify TEK led adaptive practice in bio-mulching and overall use of natural resources at the village level. At the outset, elders of each village were invited to participate in focus group discussions (FGD) on exploring and developing parameters for TEK based aspects of each bio-mulching practice. The knowledge level of male and female farmers for TEK led practices on bio-mulching was tested on a four-point scale (full knowledge assigned '3'; partial knowledge '2', minimal knowledge '1' and no knowledge '0'). The significance of difference of knowledge of each gender was tested by applying 'Z' statistics (Table 2). Using a combination of qualitative and quantitative approaches, data were analyzed and presented in Table 2.

The second objective of testing TEK led adaptive practices empirically was carried out at Krishi Vigyan Kendra (KVK) Farm, as well as on 18 farmers' fields during 2008-10. Three years' data were pooled to draw inferences from the study. Prior informed consent (PIC) was obtained from each farmer to publish their knowledge relating to adaptive practices on TEK led bio-mulching.

Healthy rhizomes of ginger (cv 'Rio-de-Janeiro') of 60 gm weight were planted out in the 1st week of April in all three years, in well-drained soil with *p*H 5.3. Spacing was kept at 30 x 45 cm. Soil organic carbon (OC) was 1.36%. Available soil nitrogen was 211.50 kg/ha (all.$KMnO_4$), phosphorus (P_2O_5) 29.5 kg/ha (Bray's P_1) and potash (K) 197.50 kg/ha. The recommended scientific agronomical package of practices was followed during the cropping season. The experiment was laid out following a randomized block design (RBD), with four treatments and three replications in 12 m^2 plots. The treatments, applied at the time of planting, were control (no mulch) and mulching with various forest plant leaves: Oak (*Quercus leucotrichophora* A. Camus; Fagaceae); chir pine (*Pinus roxburghii* Sarg.: Pinaceae)', local mixed grasses; and animal wastage (cow dung and urine) (Figs. 1 a,b,c,d). The bio-mulch was applied @ 15toone/ha in all mulching treatments. Plant height, stem diameter, rhizome length, rhizome width and number of fingers/ plant were recorded, and at harvest, yield was recorded in plot size and converted into quintal/hectare .Bacterial wilt; soft rot and leaf spot, all common diseases, were diagnosed on the basis of symptoms produced in the field. Isolation and identification of the bacterial pathogen was done on a TZC (triphenyl tetrazolium chloride) medium while the fungal pathogens were cultured on OMA (Oat Meal Agar) and PDA (Potato Dextrose Agar) medium. All disease incidences were recorded and converted into percentages for every year. Experimental data from the three years were pooled together characters wise, and then analyzed to obtain the final results.

Results and discussion

TEK based adaptations on bio-mulching in ginger crop

It is identified four major adaptive practices in bio-mulching for organic ginger production based on TEK and local resources available to farmers in Champawat district, Uttrakhand: using the leaves of oak (*Quercus oblongata* D.Don syn. *Quercus leucotrichophora* A. Camus), the needles of chir pine (*Pinus roxburghii* Sarg.), local mixed grasses, cow dung and fodder wastage of animal mixed together (Table 1). Almost all the farmers who apply these practices are resource-poor and live in rain-fed agroecosystems. The range of maximum temperature of studied district varies from 15.72 - 29.25 °C, while minimum temperature ranges from 4.24 - 19.9 °C. Similarly, on average the rainfall of last five years

Table 1— Farmers whose land were chosen for conducting study on testing TK led bio-mulching

Name of the farmers	Size of land holding (in ha) under ginger	Education	Annual income (in Rs.)	Types of landscape and soil (biophysical attributes)	Types of adaptation in bio-mulching
Balwant Singh	0.05	High school pass	50,000	Soil is sandy light red, to yellow, depth 1-1.5 feet. Rain-fed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak, teak.	Fresh oak leaf, fresh mix grasses and animal wastage, oak green leaves and dry grasses mixed with cow dung
Chatur Singh	0.03	High school pass	30,000	Soil is sandy loam, light red to yellow, depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak, teak.	Fresh oak leaves and mixed with grasses and animal wastage.
Ganga Singh	0.025	High school pass	25,000	Soil is clay-loam, light black, depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine and oak, teak.	Dry chir pine leaves
Heera Singh Bohra	0.035	Junior school pass	35,000	Soil is sandy loam and light red, to yellow, depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Mixed grasses with cow dung and urine
Jagdish Chander Joshi	0.04	High school pass	40,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Green oak leaves with cow dung and with urine
Jagdish Singh	0.02	High school pass	20,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Dry oak leaves
Kedar Singh Bohra	0.035	Junior school pass	35,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Dry grasses with cow dung and urine

(Contd.)

Table 1— Farmers whose land were chosen for conducting study on testing TK led bio-mulching *(Contd.)*

Name of the farmers	Size of land holding (in ha) under ginger	Education	Annual income (in Rs.)	Types of landscape and soil (biophysical attributes)	Types of adaptation in bio-mulching
Mohan Chander Joshi	0.04	High school pass	40,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Dry grasses with cow dung and urine
Prahlad Singh Bohra	0.025	Primary school pass	25,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Dry oak leaves
Pushkar Chander	0.05	High school pass	50,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Dry oak leaves
Rajender Singh	0.04	Primary school pass	40,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Dry chir pine leaves
Ramesh Chander	0.045	High school pass	45,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Green oak leaves with cow dung urine
Ramesh Chaube	0.035	Primary school pass	35,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Dry grasses and chir pine
Ramesh Kharkwal	0.025	High school pass	25,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Dry grasses mixed with cow dung and urine

(Contd.)

Table 1— Farmers whose land were chosen for conducting study on testing TK led bio-mulching *(Contd.)*

Name of the farmers	Size of land holding (in ha) under ginger	Education	Annual income (in Rs.)	Types of landscape and soil (biophysical attributes)	Types of adaptation in bio-mulching
Yashodhar Gahtori	0.03	Junior school pass	30,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Dry oak leaves
Yasodhar Pangaria	0.045	High school pass	45,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Dry oak leaves
Taradutt Kharkwal	0.04	Junior school pass	40,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Dry chir pine, mixed grasses with cow dung and urine
Bhuvan Dungaria	0.03	High school pass	30,000	Soil is sandy with pebbles, light yellow, and depth 1-1.5 feet. Rainfed ecosystem. Rain dependent crops. The major crops grown are soybean, potato, finger millet, and French bean. The major tree species around the agricultural fields are chir pine, oak and teak.	Dry chir pine, mixed grasses with cow dung and urine

Table 2— Knowledge status of gender in TEK-led adaptive practices on bio-mulching prepared from various local resources

Components of adaptive practices	Mean knowledge score of male	Mean knowledge score of female	'Z' value
Identification of species in bio-mulching	1.12	2.95	8.94**
Collection techniques of resources for bio-mulching	0.98	1.68	6.45**
Identification of real and matured age of species parts to be used in bio-mulch	1.0	1.74	7.98**
Local methods applied in processing the resources	1.35	2.90	10.23**
Identifying the real stage for application of bio-mulch	1.10	2.60	11.20**
Determination of bio mulch amount according to need of soil and crop	1.15	2.78	6.60**
Spreading techniques of bio-mulch prepared from traditional resources	0.90	1.90	7.80**

** Significant at 0.01% probability level

(2008 - 2012) was recorded as ranging from 246.52 - 351.05 mm. The meteorological data variable weather conditions, has a direct bearing on agricultural resources (soil, water and crops). Under such circumstances – where agriculture is rain-dependent, irrigation is not available, soils are light, landscape is undulating and overexploitation of natural resources are accelerated , external intervention to promote adaptation would need considerable empirical testing with farmers. Different types of landscape in Uttarakhand need different kinds of placed-based adaptations; farmers' TEK led adaptive practices are highly localized and have evolved over a long time period of informal experimentation. These practices can form a basis for development of more formal technologies.

Fig. 1— a= Leaves of *Banj* (oak) leave (*Quercus leucotrichophora* ; 1b= Tree of *banj*; 1c *Chir* pine tree; 1d= fallen dry pines of *chir* tree; 1e Local mixed grasses; 1f= animal wastage mixed with leaves of oak; 1g= ready mulch spread in soil

The ginger beds are covered with leaves and twigs of oaks, pines, dry grasses and shrubs available from nearby fields and community forest @ 5-10 toone/ha on a dry weight basis[5]. Sometimes, the leaves are mixed with cow dung and urine. This practice helps to conserve soil moisture during the later part of the cropping season following the monsoon period. Most often, the first mulching is done at the time of seeding, with dry leaves dropped by the trees @ 10-12 tonne/ha. Some farmers (about 15-20%) repeat mulching with 5-6 tonnes/ha of leaves at about 50-80 days after seeding or immediately after weeding.

The farmers' knowledge of ecological processes, accumulated over generations, has allowed them to select those adaptive practices which are cost effective, sustainable, climate resilient and locally available. Women play a pivotal role in all of these practices, from collecting organic mulching materials to the final processing and application of bio-mulch; in all, their knowledge of bio-mulching is significantly greater than that of men, and they contribute about 95% of the total time and energy involved (Table 3).

Relative effects of different bio-mulching practices on growth of organic ginger

Significant differences were observed in the growth ginger between treatments (including the control) under the influence of various bio-mulching material, based on selected parameters (Figs. 2 a,b & Figs.3 a,b,c,d,e). Plant height (78.40 cm), stem diameter (0.62 cm), rhizome length (6.50 cm), rhizome width (3.80cm) and rhizome fingers/plant (35.30) were observed to be the greatest with oak leaf mulching. It was at par with the mulch prepared from animal wastage and mixed with leaves, and significantly different from other treatment based on mulches prepared from leaves. Significantly higher production values were found in oak leaf bio-mulch treatment probably because of its higher efficiency in disease reduction, besides providing soil nutrients through more effective supplementation of nitrogen (N) optimizing soil temperature, suppressing evaporation losses and greater retention of soil moisture [9].

Effect of different traditionally used bio-mulching on severity of disease

All the traditional bio-mulch treatments reduced the susceptibility to the major diseases of ginger namely: bacterial wilt, soft rot and leaf soft. However, major differences were recorded in level of reduction (Fig. 4). The chir pine leaf mulching was found to be very effective against the bacterial wilt and soft rot in ginger as compared to the other bio-mulches. The greatest reduction for all the diseases was noted in

Table 3—Location specific traditional ecological adaptive practices in organic ginger production

Type of agro-ecosystems	Climate	Types of farmers	Traditional adaptive practices in bio-mulching	Adaptive process	Gender role
Rainfed	Temperate	Resource poor farmers with poor irrigation facilities and low adaptive capacity for external inputs. But these farmers are rich in knowing ethno taxonomy of soil and location specific adaptive traditional practices for various crops	Oak (*Quercus leucotrichophora* A. Camus, family: Fagaceae (Beech family)	Dry leaves of oak are collected from community forest and stored in agricultural field. The dry leaves are mixed with cow dung and applied in ginger field at the time of need.	About 95% activities are carried by women starting from leaf collection to final stage of bio-mulching. Male only ply role in load carrying and spreading the mulch material
Rainfed	Temperate	Farmers with poor irrigation facilities and low adaptive capacity for external inputs	Chir pine- (*Pinus roxburghii* Sarg.), Family: Pinaceae,		About 95% activities are carried by women starting from leaf collection to final stage of bio-mulching. Male only ply role in load carrying and spreading the mulch material
Rainfed	Temperate	Farmers with poor irrigation facilities and low adaptive capacity for external inputs	Local mixed grasses (*Chrysopogon fulvus* (Spreng.) Chiov., [*Cymbopogon distans* (Nees ex Steud.) W.Watson], *Setaria glauca* L.., [*Heteropogon contortus* (L.) P.Beauv. ex Roem. & Schult.], *Shrubs* (*Eupatorium odoratum* L.)	During May-June wild grasses are collected from forest and agricultural field. Stored and use as fodder and mixed with cow dung	In 95% cases, it is the women who harvest different species of grasses which are being adapted for feeding the animal. The waste material are mixed with cow dung and used as bio-mulch. Male only help in load carrying and spreading the mulch material in ginger field. Sometimes, the dry material of such grasses is directly used in case of small size of ginger field.
Rainfed	Temperate	Farmers with poor irrigation facilities and low adaptive capacity for external inputs	Animal wastage fodder leaves for mulching		Women mix fodder leaves with cow dung and other kitchen wastes. Then after it is left for few days for decomposition. After the partial or sometimes full decomposition, the mulch is spread in ginger field. Male only helps in load carrying and spreading the mulch material in field

chir pine leaf mulching (17.50 %), followed by mixed-leaf mulching (18.60%), whereas in the control, there was a 35.8% incidence of one or more these diseases, with a significant reduction of yield in ginger rhizomes. Mulching with oak leaf and twigs, chir pine leaves, and mixed leaves @ 5-10 toone/ha resulted in increased sprouting growth, reduced weed growth and reduced soft rot incidence. Similar results are reported from other studies [9,17]. Similarly *chir* pine leaf mulch was found better for antimicrobial activity against soft rot and leaf soft, and some other bacterial species associated with *Staphylococcus* and *Streptococcus*[17]. Overall, chir pine leaf bio-mulching produced a significant reduction in most of the ginger crop diseases as compared with the control (non-mulched) treatment.

Effect of different mulching on yield, benefits and Benefit: Cost ratio

The yield of ginger rhizomes ranged from 120.50 to 211.50 q/ha (Fig. 5). Each of the bio-mulching applications resulted in significantly different rhizome yields, both amongst different mulch treatments and compared to the control. The highest rhizome

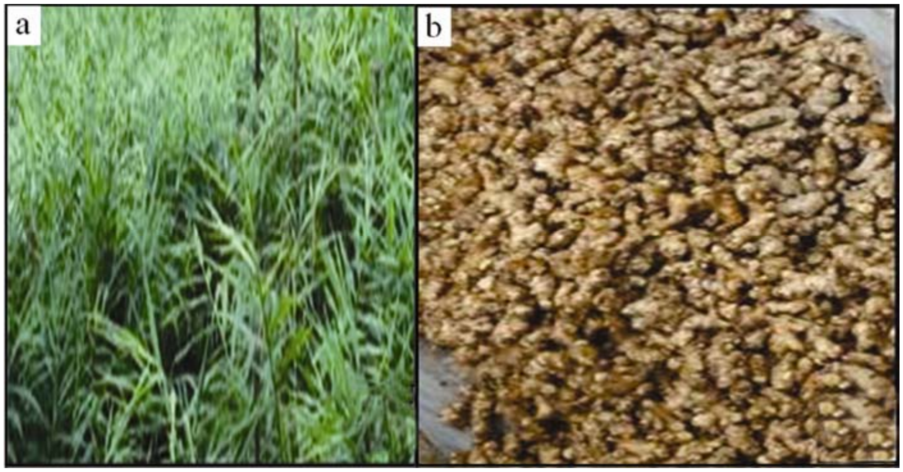

Fig. 2 (a, b) —View of crop growth and quality rhizome production on traditionally used bio-mulching

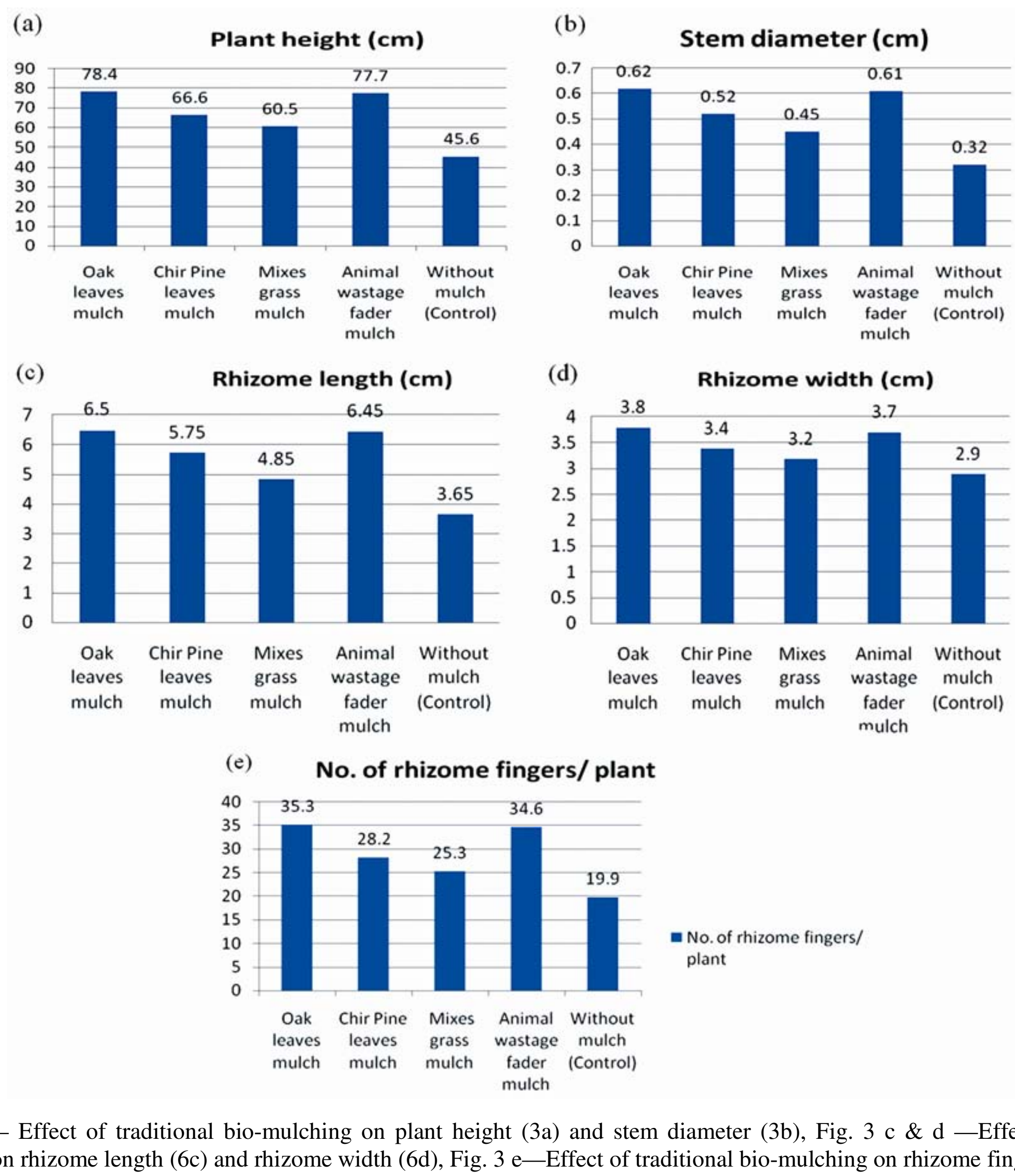

Fig. 3 a & b— Effect of traditional bio-mulching on plant height (3a) and stem diameter (3b), Fig. 3 c & d —Effect of traditional bio-mulching on rhizome length (6c) and rhizome width (6d), Fig. 3 e—Effect of traditional bio-mulching on rhizome finger per plant

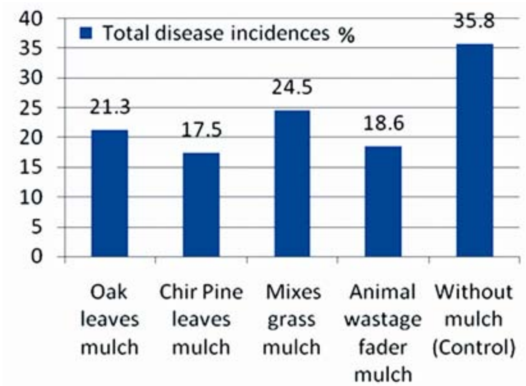

Fig. 4—Disease incidence percentage in ginger crop treated by bio-mulch

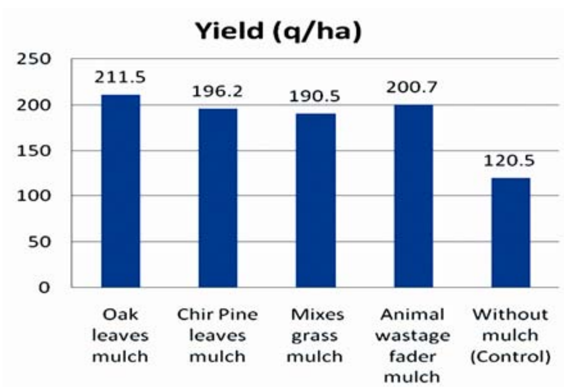

Fig. 5—Impact of traditional bio-mulch on yield of ginger crop

yield was recorded for oak leaf based mulching (211.50 q/ha). The lowest yield was recorded from the control plots (120.50 q/ha). As reported, pests and diseases are major limiting factors in ginger productivity[18].

The highest economic benefit was recorded with oak leaf based mulch treatment (Rs. 1.68 lakhs /ha), followed by the mixed leaf mulch (Rs. 1.50 lakhs /ha), whereas the lowest economic returns were from the control plots (Rs.0.65 lakhs /ha, Fig. 6). The Benefit: Cost (B:C) ratio in different mulching materials varied from 1.90 to 2.18 (Fig. 7). The highest B:C ratio (2.18) was noted for oak leaf mulch followed by mixed leaf mulch (2.00), with the lowest ratio for the control (1.56). The maximum benefits and B:C ratio from use of oak leaf mulch was due to the significantly higher yield as compared to other treatments. Therefore, to achieve overall higher production and higher incomes, oak-leaf mulch may be promoted in the region through formal institutions.

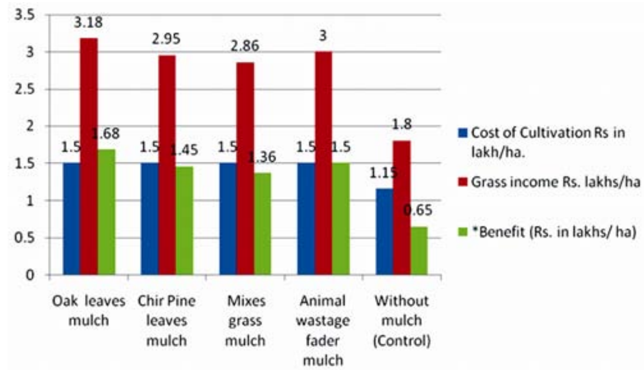

Fig. 6—Cost and benefit of different treatments on traditional bio-mulch for ginger crop

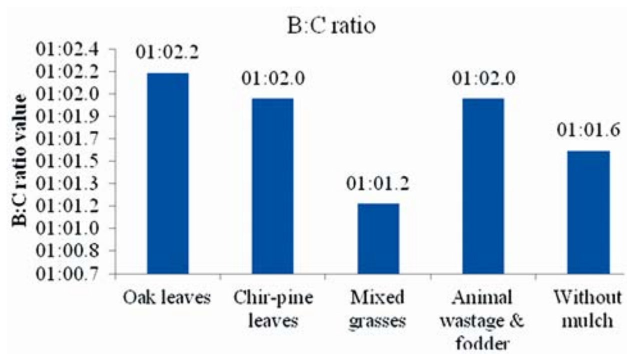

Fig. 7—Cost benefit ration of different treatments on traditional bio-mulch for ginger crop

Table 4— Effect of traditional bio-mulching on soil temperature, moisture % conservation regulation

Bio-mulch resources	Average temperature conservation in soil (OC)	Average soil moisture conservation (%)
Oak leaves	25.8	54.5
Chir-pine leaves	22.8	33.5
Mixed grasses	23.8	44.5
Animal wastage with left fodder material	24.5	48.5
Without mulch	20.4	16.5

Effect of different traditional bio-mulches on soil moisture conservation and soil temperature regulation

It is found the maximum average soil moisture conservation (54.5 %) with oak leaf mulching, followed by mulching prepared from mixed leaves (48.5 %) (Table 4). Minimum average soil moisture conservation (16.5%) was recorded in the control (no mulching). The average soil temperature regulation varied from 20.4 ^{o}C in without mulching treatment to 25.8 ^{o}C in oak leaf based mulching (Table 4). This might be because the oak leaf bio-mulch completely covers the soil surface around the crop, and therefore plays a key role as a buffer. The oak leaf mulching also helped control soil evaporation, and conserve solar energy in the lower surface of the mulch. Thus mulching can help to optimize soil moisture and assist in temperature control for higher germination and quality yield of ginger under rain-fed conditions. Similar findings were reported elsewhere[19].

Conclusion and policy implications

Our study showed that resource-poor farmers have evolved location specific traditional ecological knowledge (TEK)-based adaptive practices – in this case mulching – which are cost effective, energy efficient, locally available and ecologically sustainable. By deliberately adding organic mulches, based on their TEK, they are able to enrich soil carbon, reduce crop diseases and sustain ecological services in rain-fed agro-ecosystems. We found that, among the different traditionally used bio-mulches in our study, the highest organic ginger yield, benefits and B:C ratio were provided from oak leaf bio-mulch, while chir pine bio-mulching produced the lowest incidence of diseases in the ginger crop. Using TEK based adaptations in ginger production, farmers can generate an additional income of Rs.1.03 lakhs per hectare. However, there is still an urgent need for study of the chemical composition of these leaf-based mulch and associated soils and crops. This may help us to better understand their effectiveness against bacterial wilt and soft rot pathogens of ginger crops. This study provides an opportunity to agronomists and agricultural biochemists for working on the organic and biochemical dynamics, and their role in soil health and crop management under rain-fed agroecosystems. However, chemical composition of leaves of oak, chir pine and other grasses need to be studied in detail in relation to its effectiveness against the bacterial wilt and soft rot pathogens of ginger other than role in mineralization and maintain soil health. Such adaptation can further be excelled and promoted if refinements in practices are made, and also these adaptations are integrated with the conservation and sustainable adaptation policies of government. For an instance, the Himachal Pradesh government is working on $REDD^+$ policy for his mountain state to get benefit on carbon credit[20]. This policy has scope to provide economic incentives to farmers if they are maintaining certain area under certain perennial tree species. Such incentives based policy need to be worked out according to the need and diversity of socioecological systems of a state. The TEK led adaptive practices with promising solutions can also be mainstreamed with science, policy and practice of climate change adaptation.

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