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Climate change impact on insect pest prevalence and sustainable adaptation strategies for their management.
Impacto del cambio climático en la prevalencia de las plagas de insectos y las estrategias de adaptación sustentables para las mismas.

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ABSTRACT

Climate change has a pronounced impact on agriculture. A pan-India study on climate change impact on insect pest prevalence was conducted on paddy, cotton, pulses, wheat, mustard and barley cultivating marginalized farmers (n=280). The systematic random sampling methodology was adopted for sample population identification. A specially designed, developed and field tested questionnaire was used to elicit the information from the respondent. The findings revealed that during the crop growth stage insect pest prevalence has increased, new types of insects affecting the crops, more weed growth affecting the crops, and the cost of insecticides and pesticides use has increased several folds. To manage these insect pests, synthetic insecticides and pesticides are used which have the number of disadvantages associated with them. To overcome these, sustainable adaptation strategies for insect pest management are identified from the literature and are described in this paper. These strategies include intercropping, poly-culture, cover crop, rice-fish agriculture system, organic mulches, bio-fumigation, trap cropping etc. Farmers' awareness, training, and workshops are required for the dissemination of these strategies for insect pest management for transforming subsistence farming into sustainable farming.

Keywords: climate change, climate-smart agriculture, insect pest, intercropping, sustainable adaptation

RESUMEN

De modo que el cambio climático tiene un efecto marcado en la agricultura, se realizó un estudio en todo la India sobre el cambio climático en la prevalencia de las plagas de insectos en los agricultores marginados de arroz con cáscara, algodón, leguminosas, trigo común, mostaza y cebada (n=280). Se adoptó una metodología de muestreo aleatorio sistemático para identificar la población de la muestra, de manera que se empleó un cuestionario especialmente diseñado, desarrollado y probado en condiciones reales para obtener información del encuestado. Los resultados revelaron que, durante la etapa de crecimiento de cultivos, la prevalencia de las plagas de insectos ha aumentado, por lo que tipos nuevos de insectos y un aumento de maleza están afectando los cultivos, además, el costo del uso de insecticidas y los pesticidas se ha incrementado múltiples veces. A fin de controlar estas plagas de insectos, se utilizan insecticidas y pesticidas sintéticos que poseen una serie de desventajas asociadas. Para solucionar lo anteriormente mencionado, estudios reconocen a las estrategias de adaptación sustentables para controlar las plagas de insectos, las cuales se describen en este artículo. Estas estrategias abarcan el cultivo intercalado, el policultivo, el cultivo de cobertura, la rizipiscicultura, las cubiertas orgánicas, la biofumigación, el cultivo trampa, etc. Se requiere concientizar, capacitar y brindar cursos prácticos a

los agricultores, y así, diseminar estas estrategias para el control de plagas de insectos y transformar la agricultura de subsistencia en una agricultura sustentable.
Palabras clave: cambio climático, agricultura climáticamente inteligente, plaga de insectos, cultivo intercalado, adaptación sustentable

INTRODUCTION

Climate change projections for India indicate an overall increase in temperature by 1-4ºC and precipitation by 9-16% towards the 2050s (Krishna Kumar *et al*., 2011). This leads to increased frequency of extreme events such as droughts, floods, and cyclones which will have adverse impacts on agriculture (Rama Rao *et al*., 2016). Climate change will also have an economic impact on agriculture, including changes in farm profitability, prices, supply, demand, trade and regional comparative advantages. The two-way relationship of climate change and agriculture is of great significance in particular to developing countries due to their large dependence on agricultural practice for livelihoods and their lack of infrastructure for adaptation when compared to developed countries. Agricultural activities are affected by climate change effects due to their direct dependence on climatic factors (Singh *et al*., 2016).

India has a net cultivated area of 142 million hectares (Mha), out of which, about 54% is rain-fed (Sikka *et al*., 2016). Agriculture plays a vital role in the Indian economy and is the home of small and marginal farmers (80%) (Landholding ≤ 1.0 hectare) (Dev, 2012). The total contribution of agriculture to the gross domestic product of India as given by The Economic Survey (2016–2017) is 17.1% which is very significant. Indian farmers are more vulnerable to climate change because of small landholdings, lack of financial resources, technologies, infrastructure, and institutions to cope with climate change shocks (Shirsath *et al*., 2017). Rain-fed agriculture will be primarily impacted due to rainfall variability and a reduction in the number of rainy days (Venkateswarlu and Shanker, 2012). According to the United Nations Commission on Sustainable Development, one farmer committed suicide every 32 minutes between 1997 and 2005 in India. The marginal operational holdings had done more suicides in India (50.3%) followed by small (25.9%) whereas, least by large farmers (7.9%) (Manjunatha and Ramappa, 2017).

The climatic impact on agriculture will be heterogeneous and ambiguous (Knox *et al*., 2012) and vulnerability will vary between crops and regions and with people's socio-economic conditions including inequality and oppression (Kates *et al*., 2012, Dow *et al*., 2013, Jayaraman and Murari, 2014) and because people involved in agriculture tend to be poorer compared with their urban counterparts. During crop production and productivity, insect pests, weeds and nematodes are important limiting factors that affect crop growth and yield output. Modern insect pest management techniques involve the use of agrochemicals. The heavy dependence on insecticides and pesticides has dire consequences on the environment, farmers' health, increase production cost, bioaccumulation and biomagnification, pesticide resistance, residue in food products, and decreased effectiveness of pesticides in addition to the vulnerability of marginalized farmers to climate change. The climate change impacts on pests may include a shift in the species distribution (Chandra, 2012). Thus, there is an urgent need for sustainable adaptation strategies for insect pest management which will overcome the above-mentioned limitations.

There is a paucity of literature on studies carried out on the climate-change impact on insect pest prevalence on marginalized farmers and sustainable adaptation strategies to overcome this. Thus, to fill this identified gap this study was intended to carry out to assess climate change impact on agriculture regarding insect pest prevalence and to add new knowledge in this subject domain concerning sustainable adaptation strategies to manage them.

METHODOLOGY

To ascertain the impact of climate change in agriculture on marginalized farmers a pan India study on crops viz. paddy, cotton, pulses, wheat, mustard, and barley was carried out from Maharashtra and Rajasthan states of India. The sampling locations (districts) were identified based upon different crops cultivated by this group of farmers. The districts identified from Maharashtra include Chandrapur (Paddy), Amravati, Wardha and Yeotmal (Cotton), Beed, Latur, Osmanabad and Parbhani (Pulses). In the case of Rajasthan, Alwar and Jhunjhunun districts (Wheat, Mustard and Barley) were identified. The selection of the study area is based upon the Vulnerability of Indian Agriculture to Climate Change (2071-2098) report (Rama Rao *et al*., 2013). Of the two states selected for this study, 10 administrative blocks from 10 districts were identified and 29 villages were included. Of the identified sampling locations, the sample population (n = 280) from identified villages was collected by adopting the systematic random sampling methodology. The inclusive criteria were those farmers who have landholding ≤2.5 acres (≤1 hectare) and are engaged in agriculture activities for ≥15 years. Attempts were made to incorporate both genders in the study; however, due to field constraints, only a few female farmers could be included.

A specially designed & developed and field-tested interview schedule was constructed to elicit information on various dimensions of climate change impact on agriculture. The Likert scale was used for the responses of the questions to get quantitative and comparable responses. The identified farmers were made aware of the study and ensured the confidentiality of the responses made by them. One-to-one interviews were carried out. The questionnaire was explained in the local languages (Marathi and Hindi) to get the proper responses. The responses were marked by Research Assistant to avoid any mistakes. In addition, Focused Group Discussion was attempted to collect in-depth information on climate change impact. Photographs were also taken to support the observations. The collected data was analyzed with the help of SPSS, and Microsoft Excel®.

RESULTS AND DISCUSSION

The climate change impact on paddy, cotton, pulses, wheat, mustard, and barley cultivating marginalized farmers in different parts of India in the crop growth stage is presented in Table 1. From the table, it can be stated that insect pest attack, weed growth, and the cost of pesticides/insecticides increase are the major impact of climate change on agriculture during the crop growth stage. Less irrigation water increased insect pest attacks. Furthermore, new types of insect affecting crops and more weed growth have emerged as major problems. The attack of new pest observation corroborates with Rosenzweig *et al*., (2001), Elphinstone and Toth (2008) and Petzoldt and Seaman (2010). The insect pests associated problems are presented in Table 2. It is found that weather is one of the responsible factors for an increased prevalence of insect pests. Furthermore, the effectiveness of insecticides/pesticides is decreased and the resistance capacity of insect pests increased. Moreover, to manage these insect pests and weeds increase in the use of insecticides, pesticides, and weedicides has resulted in an escalation in their cost several folds. The increase in the cost of insecticides and pesticides for various crops in various range groups and maximum increase in cost is reported in 0-20% range with an average increase of 51% (Table 3). The insect pest prevalence has posed a serious challenge for the marginalized farmers agree with the findings reported by Pareek *et al*., (2016). Owing to the poor socio-economic status of this group of marginalized farmers and with limited access to finance, technology, infrastructure and institution are facing dire consequences of climate change. The adaptation of sustainable adaptation strategies to overcome these climate-change-induced impacts is the need of the hour.

Table 1: Climate change impacts on insect pest prevalence

Paddy	Cotton	Pulses	Wheat, Mustard, Barley
Insect/pest attack increased (98.57)	Insect/pest attack increased (91.42)	Insect/pest attack increased (100)	Insect/pest attack increased (100)
Less irrigation water resulted into insect pest attack (98.57) New types of insects affecting crop (86.14)	Cost of pesticide/insecticide use in farm increased several folds (91.42)	Less irrigation water resulted into insect pest attack (100)	Cost of pesticide/insecticide use in farm increased several folds (100)
More weed growth affecting crops (45.71)	Less irrigation water resulted into insect pest attack (91.42)	Cost of pesticide/insecticide use in farm increased several folds (97.89)	Less irrigation water resulted into insect pest attack (100)
	Weed growth more during cropping in recent years (48)	Weed growth more during cropping in recent years (73.68)	New type of weed growth observed in recent years (78)
	New types of insects affecting crop (89.99)	New type of weed growth observed in recent years (67.36) New types of insects affecting crop (98.94)	Weed growth more during cropping in recent years (56) New types of insects affecting crop (88)

The values in parenthesis are in percentage of responses. (Tikadar and Kamble, 2021a,b,c)

Table 2: Insect pest associated problems

Paddy
Pesticide use has increased as the insect pests are becoming more resistance to pesticides/insecticides due to climate change. Cloudy/foggy weather attracts more insect pests which causes crop loss.
Cotton
Effectiveness of pesticide is reduced thus doses or quantity of pesticide increases which cost more. Due to uneven rainfall the pesticide spray on crops is washed out which makes crops more susceptible to insect pests attack. Weed killer spray reduces the soil fertility but no other options due to increase weed growth. Earlier weed used to be consumed by livestock; however, recent weeds are poisonous and remain in the field. Due to insecticides/pesticides spray inhalation by the farmers their death are increasing.
Pulses
Heavy rain during harvesting attracts insect pests.

Table 3: Cost of insecticides/pesticides increase

Crop	Range of increase in cost of insecticide/pesticide		
	0-20%	21-40%	41-60%
Paddy	22%	39%	39%
Cotton	40%	50%	10%
Pulses	59%	31%	1%
Wheat, Mustard, Barley	82%	14%	4%
Average	51%	34%	14%

(Tikadar and Kamble, 2021a,b,c)

Sustainable adaptation strategies for insect pest management

Sustainable adaptation strategies are the practices that improve agriculture production and incomes, adapt and contribute to system resilience, and at the same time reduce or remove greenhouse gases (FAO, 2013) holds a promise to improve agriculture productivity. The various sustainable adaptation strategies for insect pest control are presented in Table 4. Some of these strategies are described in brief.

Table 4: Sustainable adaptation strategies for insect pest management

- Intercropping garlic and tobacco
- Polyculture system
- Cover cropping
- Pest and disease resistance seeds
- Jatropha oil or jatropha curcas shrub
- Pyrethrin from dried flower of *Chrysanthemum cineraria folium*
- Biocontrol and chemical herbicides
- Develop pest & disease forecasting system
- Organic mulches
- Rotation of crop
- Organic amendments for nematode management
- Mixed intercropping
- Relay intercropping
- Row intercropping
- Stripe intercropping
- Trap crop
- Dead and trap cropping
- Genetically engineered trap cropping
- Perimeter trap cropping
- Sequential trap cropping
- Multiple trap cropping

• Seed treatment with chemical • Shallow seeding (2-3 cm depth) • Soil compaction prevention • Soil drainage improvement • Bio-fumigation • Straw mulch	• Push-pull trap cropping • Trap crop for root-knot nematodes management • Companion planting • Habitat management • Allelopathy or allelochemicals • Pheromone trap

Intercropping

Intercropping involves the cultivation of two or more crops at the same time in the same field. Various combinations of intercropping include mixed intercropping, relay intercropping, raw intercropping, and strip intercropping. This methodology increases the diversity in an agro eco-system and reduces the damage by insects, pests, and weeds by disrupting the ability of the pests to find their host (Andow, 1991). The mixed cropping of spring-barley/oats and winter-rye/winter-wheat reported a reduction in fungal leaf diseases (Vilich-Meller, 1992). Incidence of diseases reported reduction (53%) in intercropping cultivation (Francis, 1989). The intercropping of potato with maize and cowpea effectively reduced bacterial wilt incidence. Moreover, intercropping of tomato with garlic, marigold, maize, sorghum, and onion decrease the bacterial wilt and increase the crop stand. Intercropping system viz. broadcast, mixed, row, cropping and sole delayed the onset of the epidemic, reduces bacterial blight and diseases progression rate (Fininsa and Yuen, 2002).

Furthermore, for nematode management intercropping system can also be effective. The banana nematode can be managed by intercropping of marigold and reduction in the population of *Pratylenchus* sp. by 85% (Sundararju *et al*., 2002). For suppression of weed population density and biomass production, intercropping systems are considered effective. In temperate zone, cropping systems forage grass and legume species have been extensively used. Unamma *et al*., (1986) reported maize/cassava intercropping with cowpea and egusi melon gave adequate weed suppression during the critical period. Intercropping black gram 21 days after planting rice effectively suppressed weed growth (Sengupta *et al*., 1985). Weed growth suppression by 22-38% was observed by intercropping pigeon pea with green gram (Ali, 1988). Maize/cowpea intercropping with squash suppressed weeds (Chacon and Gliessman, 1982).

The garlic intercropping in tobacco showed that the pest significantly decreased in intercropping systems. The complete elimination of aphid abundance even when there were peaks in their population was possible. A significant decrease (30%) in tobacco mosaic virus occurrence was observed in intercrop versus mono-crops. The economic benefit showed an increase from 52.1% to 80.2% depending on the type of intercropping system. The garlic has insecticidal or repellent properties (Bakri and Douglas, 2005) helps to control insect pests and diseases. In addition, onion can also be used as an intercrop resulting in greater yields.

Polyculture

Polyculture has emerged as an alternative cropping system to reduce pest damage on rice and at the same time increase the diversity of crops. Polyculture results in crop diversity and ensures at least one crop will be harvested at the end of the harvest season (Lithourgidis *et al*., 2011; Tuomisto *et al*., 2012). Crop diversity reduces stress as compared with one or few species (Steudel *et al*., 2012).

Rice-fish agriculture system

In the rice-fish agriculture system, rice fields are irrigated with stream water where fish swim. This results in the creation of an ecological symbiosis. The fertilizer and nutrition are provided by fish to the rice, consume larvae and weeds and regulate micro-climate conditions. This system reduces the labour cost required for fertilization application and pest control. The high levels of oxygen are maintained in water due to disturbance caused by the fish's activities which are required for fish growth. This system generates favourable conditions which help to conserve other crop species (GIAHS, 2013).

Cover crop

Cover crop helps to reduce weeds and improve diversification in annular or perennial crops. Furthermore, reduces pests while increasing pest predators. Cover crops also reduce runoff and soil erosion problems resulting during heavy rainfall, moreover, drought conditions help in reducing evaporation (Peng 2006; Song *et al*. 2006; Peng *et al*. 2007). Cover crops provide shelter to pest predators thus reducing the issue of pest damage (Chen *et al*. 2011; Chen 2011).

The bacterial and fungal pathogens population can be controlled by breaking their life cycle by using cover crops. The growing cover crops like sorghum and kudzu (*Pueraria phaseoloides*) reduce the bacterial blight in bananas. Cover crops such as cereal rye and flowering rapeseed as mulches can delay the onset of early blight in tomatoes. Growing oats as a cover crop can also reduce vegetable crop diseases caused by *Rhizoctonia* spp. (Sustainable Agriculture Network, 1998). Cabbage root fly intensification can be decreased significantly by growing a green manure cover crop. Planting of clover and other legume ground cover is used to manage leafhopper pests in grape vineyards by attracting beneficial wasps and spiders by providing them with habitat and food sources.

Non-host cover crops like Siratro can be grown in the interspaces of black pepper to reduce the population of root-knot nematodes. *Brassica* green manure cover crops are used to manage sugar beet cyst nematodes which act as a trap crop for them (Thorup-Kristensen *et al*., 2003; Schlathoelter, 2004; Matthiessen and Kirkegaard, 2006).

Organic mulches

Straw, hay, leaves and chipped brushes forms organic mulches that are most effective for weed control and insect pest suppression. To reduce the Colorado potato beetle's ability straw mulch is used. When soil is covered with organic mulches natural enemies of aphids that predate on them increase in number and diversity. The damage due to insect pests on vegetables can be reduced to 70% with the help of spiders which have hay and straw mulch as habitat. The damage to crops by white grubs—a plant-eating insect can be minimized by organic mulches. The weed seed germination in hairy galinsoga (*Galinsoga ciliate*), bluegrass (*Poa annua*), common ragweed (*Ambrosia artemesiifolia*), common chickweed (*Stellaria media*), common purslane (*Portulaca oleracea*) can be reduced by the application of a thick layer of mulch of leaves, straw or hay which blocks the solar radiation to reach to the weed's seed (Egley, 1996) and lower soil temperature and dampen daily fluctuations.

Trap cropping

Trap cropping is grown in smaller areas before or with the main crop, which is more attractive than the main crop to trap the pest. The trap crop is uprooted and destroyed before it matures thus protecting the main crop from pests (Hokkanen, 1991; Shelton and Badenes-Perez, 2006). The type of trap cropping includes traditional, dead-end genetically engineered, perimeter, sequential, multiple, push-pull, biological control assisted and semio-chemically assisted. To manage the Lygus bugs on cotton, alfalfa can be used (Godfrey and Leigh, 1994), and squash can be used to control pests on cucurbits (Pair, 1997). The African marigold can be used as a trap crop for the management of tomato fruit borer (Srinivasan *et al*., 1994). For the control of red sunflower seed weevil planting of early-maturing sunflowers proved effective (Brewer and Schmidt, 1995). In sequential trap cropping, trap crops are grown before or after crash crops. Various trap crops are grown simultaneously for the management of multiple crop pests. Trap crops are also useful for root-knot nematode management in the roots of *Vigna unguiculata* and *Crotolaria* species (Cook and Baker, 1983). Previously planted marigold trap crop effectively controlled root-knot nematode of tomato seeds and healthier seedlings (Rangaswamy *et al*., 1999).

Companion planting

In companion planting, several crop plants are grown together for insect-pest, nematode, and weed management. These plants deter the pest by the production of natural toxins/poisons and masking the plants. The parasitic weed in the maize crops can be suppressed by desmodium (Midega *et al*., 2014). Cruciferous and leafy vegetation crops are damaged by caterpillars. To manage the caterpillars' various plants which attract aphids can be employed viz. peppermint, lemon balm, chamomile, and leafhoppers can be managed by companion plants viz. English lavender, sweet alyssum, buckwheat, and statice.

Push-pull strategy

For the management of stem borers and parasitic weeds on corn, a push-pull stimulo-deterrent diversion strategy has been developed. In this methodology, green leaf desmodium is used for driving away from the steam borers ('push') and Sudan grass which is grown at the edge serves as 'pull' for female moths to lay eggs.

Similar methodologies have also been developed for lepidopteron pest management in cauliflower and cabbage, and fruit borer in tomatoes. The herbivores are pushed away from the main crop by repellent intercrop and border plants pull them simultaneously to adjacent/borders areas. This methodology can be adopted in subsistence farming, intensive arable farming, and horticulture. The main, inter and border crops involved in this methodology are revenue earning and providing forage to farm animals. Khan *et al*., (2011) reported a threefold increase in maize and sorghum yield and an increased cost: benefit ratio.

Biocontrol with chemical herbicide

The dried flowers of pyrethrum (*Chrysanthemum cineraria folium*) are used to produce a pyrethrin—a natural insecticide. The cereal and legume production is affected by *Stiga* spp. can be controlled by biological methods (Zahran, 2008) furthermore; Aflatoxin caused in maize can also be controlled with Aspergillus. The biocontrol agents with chemical herbicides integrated can increase pest control efficiency.

Bio-fumigation

During the decomposition of organic amendments, the release of volatile bio-toxic compounds into the soil atmosphere is known as bio-fumigation (Stapleton, 1998). During the breakdown of *Brassica*, isothiocynates (ITC)—a volatile is produced which is highly toxic to pathogens (Delaquis and Mazza, 1995) is released. Black mustard and Indian mustard can be used for the production of substantial quantities of ITC (Tollsten and Bergstom, 1988). Glucosinolates containing plants can be utilized as intercrops or rotation crops. The fresh plant material can be used as green manure or utilizing processed plant products to preserve ITC activity. Biofumigation products are used for the control of pathogens such as *Rhizoctonia solani*, *Botrytis cinerea*, *Didymella lycopersici*, *Cladoporium fulvum* and *Fusarium oxysporium* (Urbasch, 1984).

Allelopathy

Allelopathy mechanism involves the release of chemical compounds into the environment by one plant which will affect the growth of another plant which includes micro-organisms also (Rice, 1984). These allelochemicals are secondary metabolites produced by-products in various physicochemical processes in plants (Bhadoria, 2011; Farooq *et al*., 2011). Multiple plants allelochemicals mixture is more effective than single-plant allelochemicals. Adult Elm leaf beetle can be completely killed by using plant extracts of California pepper (Huerta *et al*., 2010). To manage chickpea beetle, allelochemicals from black pepper, garlic, tea, and red chillies can be used (Zia *et al*., 2011). The allelopathic water extract of sunflower, sorghum, mustard, and mulberry are used to manage aphids and sucking insects of *Brassica* spp. (Farooq *et al*., 2011).

Bio-pesticide

Trichoderma spp. are used as bio-fertilizer, soil amendments and as a bio-pesticide and reduce significant diseases caused by *Pythium* spp., *Phytopthora* spp., *Fusarium* spp., and others (Punja and Yip 2003; Blaya *et al*., 2013). *Trichoderma haziannum* enhances the resistance of bean leaves to diseases caused by *Botrytis cinerea* (Elad *et al*., 1993).

CONCLUSION

The climate change impact is witnessed on agriculture. Of the various impacts, insect pest prevalence has been reported as a major one during crop growth stage. In the light of future climate change projections for India, the agriculture sector will face adverse impacts and Indian farmers due to their limited resilience will be at receiving end. Although, the use of synthetic insecticides and pesticides are common practices for insect pest control they have their limitations. For effective management of insect pests and at the same time to overcome the limitations associated with the use of synthetic insecticides and pesticides, sustainable adaptation strategies are required which will facilitate to achieve both aspects. These strategies will control the prevalence of insect pests and reduce the associated impact on the environment and further will enhance the crop yield and pave the way for sustainable agriculture. For effective insect pest management, diversification of these adaptation strategies will be requisite. The farmers may not be aware of these adaptation strategies. To make them aware of these an institutional mechanism needs to be developed. Furthermore, these adaptation strategies ‘to work’ some additional measures such as national policies and programmes, technologies, financing, capacity building, safety nets etc. are prerequisites. The farmers’ awareness and access to information in local languages regarding these adaptation strategies in collaboration with government and non-government organizations will help these strategies implementation in the field. While implementing this adaptation strategies prioritization and constrain analysis need to be carried out as the adaptation of these strategies will be governed by myriad factors.

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