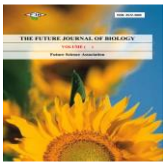

The Future of Biology

Article

A Brief overview of biological control

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Abstract: Pests are mostly to blame for significant crop losses, decreased food supplies, lower-quality agricultural output, and difficult financial times for farmers and processors. Chemical control techniques are typically used to manage them, however they are not always cost-effective or efficient and may pose unintended dangers to human health, safety, or the environment. But in order to meet the challenge of feeding the world's growing population, effective, affordable, and environmentally friendly disease control strategies are essential. By using natural enemies, biological control could be a useful strategy for minimizing or eliminating pests and their impacts. Utilizing helpful microorganisms to manage plant infections and the diseases they cause is known as biological control, and it is an environmentally sound method. The effectiveness, benefits, and safety of employing biological agents to prevent and manage pest damage to crops are outlined in this paper. It has been universally demonstrated that bio-control is safe for humans, animals, plants, and the environment. This stands in stark contrast to chemical insecticides, which are more commonly utilized and frequently cause contamination in the environment that harms both people and the ecosystem. Manufacturers of bio-control products are always creating new procedures for determining agent safety, implementing, and gauging treatment efficacy. Regulations are being developed by the government and manufacturing associations to ensure the responsible and safe application of biocontrol. The advantages of biological control systems are what propel the technology's growing popularity. The use of bio-control platforms should be encouraged for the obvious reasons of biodiversity protection and high benefit to cost ratio. To adopt these alternative agricultural approaches, the general public and those in the agriculture industry will need to be educated and made aware of them.

Key words: Biological control, natural enemies, predators, pests.

1. Introduction

Since the middle of the 20th century, chemical pesticides have been widely employed, and their use has only grown. Approximately 500 million kg are applied each year in the United States, and approximately 3 billion kg are applied globally. According to **Pimentel (2005),** high application rates have brought forth additional issues including as resistance, secondary pest outbreaks, and risks to the environment and public health. Because of these dangers and the tight laws governing chemical pesticides, more deliberate efforts at pest management are progressively using biological control **(Glare *et al.*, 2012 and Czaja *et al.*, 2015).**

The 1950s saw the development of synthetic pesticides, which made controlling insect pests simple. But it didn't take long to realize that using pesticides wasn't without its issues. Pest revival happened, certain non-target organisms suffered negative effects, and some insect pests developed resistance. Concerns about the environment and health also surfaced **(Shelton, 2019).** There are disadvantages to continuing to rely only on traditional insecticides, though. This guide's integrated pest management approach encourages the use of biological control, cultural control techniques, and pest-resistant plant cultivation as non-chemical pest management strategies. In few cases, pesticides should be used prophylactically that is, just to stop financial losses **(Shelton, 2019).**

Natural predators are alternatives to pesticides, which have well-documented detrimental effects on agricultural pest control. They can also act as biological control agents in the environment. Regarding whether such biological control may be a broadly applicable solution, there is still a great deal of uncertainty, particularly in light of ongoing climatic variation and climate change. On average, predators decreased pest populations by 73% while increasing crop output by 25%. Remarkably, the presence or absence of a particular predator species had little effect on the effects of predators. One important climatic factor influencing biological control was seasonality of precipitation; as seasonality grew, so did the influence of predators on insect populations. When considered collectively, predators' beneficial effects on yield and pest control, along with their resilience to fluctuations in precipitation, point to the possibility that bio-control will play a significant role in both pest management and food supply expansion as the planet's precipitation patterns become more unpredictable **(Boldorini *et al.*, 2024).**

Definition biological control

Biological control, often known as bio-control, is the use of live creatures (such as viruses) to combat harmful species (such as infections, pests, and weeds) for a variety of objectives that benefit humans. The procedures and ideas involved have therefore developed over the past century in several streams linked to various scientific and taxonomic fields. Concurrently, there has been a rise in the use of biological control in industrial settings and legal frameworks, leading to a breakdown of concepts and terminology **(Stenberg *et al.*, 2021).**

The use of non-chemical, eco-friendly techniques to manage illnesses and insect pests through the use of natural control agents is known as biological control. It is now acknowledged as an environmentally friendly, technically sound, commercially feasible, and socially acceptable approach to pest control. A way of controlling pests that has little effect on the environment and little chance of contaminating people, domestic animals, or the surrounding area is biological control. There are several examples of biological regulation in action all around the world **(Kaur *et al.*, 2019).**

One element of an integrated pest management plan is biological control. It is described as the natural enemies' process of reducing pest numbers, usually with human participation. Remember that, absent human intervention, all insect species are repressed by ambient variables and naturally occurring creatures. It's common to call this "natural control." While biological control of insects is the main focus of this guide, it also covers biological management of weeds and plant diseases. Predators, parasitoids, and diseases are examples of natural enemies of insect pests, also referred to as biological control agents. Insects and diseases are two examples of biological weed control agents. Most typically, biological control agents for plant diseases are called antagonists **(Shelton, 2019).**

Much greater attention must be paid to studying native natural enemies and their effects on the pests they target before biological management may proceed. With the use of this knowledge, it might be able to modify agricultural habitats, alter cultural norms, or improve pesticide application techniques in order to promote or increase the effectiveness of natural enemies. Furthermore, there is a lot of potential in introducing new natural enemies through traditional biological control programs. Although difficult, creating effective biological control systems has a lot of promise **(Shelton, 2019).**

Generally speaking, there are three types of applied bio-control depending on how the natural enemies are managed. Exotic natural enemy species are brought in and distributed in the area where the pest is present in conventional bio-control. Over a period of years, the introduced natural enemy may multiply, spread over the pest zone, and suppress the pest population if it is successful in adapting to its new environment. Usually, no additional natural enemy releases are required after those utilized to first create and disperse the natural enemy. Because exotic pest species typically enter their new habitats without the natural enemies that control their populations in their original range, classical bio-control is frequently used to combat these pests. But when it's believed that an exotic natural enemy species could be able to reduce the pest more effectively than native natural enemies, classical bio-control is also used to combat native pests **(Parra, 2014).**

Role of natural predators in controlling pests

Natural enemies present a viable ecological and financial approach for pest control **(Power, 2010).** According to **Pimentel (2005),** natural enemies are responsible for at least 50% of pest control in agriculture fields. This important ecosystem function is valued at $13 billion annually in the USA alone **(Losey and Vaughan, 2006).** It has been demonstrated that parasitic and predatory insects are excellent natural enemies in controlling pest species **(Symondson *et al*., 2002).** Due to the fact that these species live in natural groups, there is a chance that they will interact with one another in ways that could either strengthen or weaken the regulation of pests. Due to the fact that these species live in natural groups, there is a chance that they will interact with one another in ways that could either strengthen or weaken the regulation of pests. As evidenced by empirical research, trophic interactions between various natural enemy assemblages can really have a wide range of impacts, such as antagonistic, additive, null, or synergistic ones **(Letourneau *et al*., 2009).** As an example, predators and parasitoids may target a pest at different stages of the insect's life cycle in the field **(Wilby and Thomas, 2002),** which can suppress the pest more effectively than a single enemy species **(Snyder and Ives, 2003).** However, antagonistic interactions between natural enemies, like intraguild predation, may reduce this additive effect **(Martin *et al*., 2013).** This can happen, for instance, when predators consume young parasitoids found in their prey, which lessens the parasites' influence on the pest **Colfer and Rosenheim, (2001).**

The species known as predators are those that eat other animals, or prey, in order to grow, survive, and procreate. They typically outgrow their prey, are energetic, and require multiple victims to complete their life cycle. These predators locate and kill their prey using a variety of techniques, and some of their body components have been altered to facilitate their predatory gait. Predation is typically present in both the immature and adult stages (e.g., Lady Bird Beetle) or occasionally in the immature stage (e.g., Syrphid fly, Green lace wing). Depending on their nature, these predators can be either permanent (predatory mites) or migratory (ladybirds) **(Seni and Halder 2022).**

Biological control and natural enemies

Over 55.5 billion hectares, natural (biological) regulation is continuously at work in all global ecosystems. Among the 100,000 arthropod species that are potentially pests, 95% are under natural (biological) control; the remaining 5,000 arthropod pest species are the focus of all other control strategies currently in use. When compared to the meagre 8.5 billion US dollars spent on pesticides annually, the ecosystem function of natural biological control is projected to have a minimum yearly worth of 400 billion US dollars. 350 million hectares, or 10% of cropped land, are under the application of classical biological control, which has extremely high benefit-cost ratios of 20–500: 1. With benefit-cost ratios of 2–5:1, augmented, commercial biological treatment is used on 0.016 billion hectares, or 0.046% of area under cultivation. This makes it comparable to chemical pest control **(van Lenteren *et al*., 2006).**

The foundation of Integrated Pest Management (IPM) is biological control, which is crucial to the long-term and profitable eradication of arthropod pest populations **(Naranjo *et al.,* 2015).**

Sustainable insect pest control is achieved by habitat management and biological control. Various land compositions, such as a variety of landscapes and patchiness, strengthen the natural enemies and ultimately help manage insect pests. Features of the plant, such as the colour, shape, and timing of blooming, guarantee an abundance of food for natural enemies like pollen and nectar. Furthermore, a few farming techniques including tillage, crop rotation, and intercropping affect natural enemies, particularly predators and parasitoids. As a result, they lengthen the life span and fertility of parasitoids and predators, which aid in the management of insect pests **(Akter *et al.,* 2019).**

Although it has received the least attention, it is widely agreed that the most crucial biological control technique is the conservation of natural enemies. The explanation is straightforward: biological control and contemporary agriculture are diametrically opposed. A number of tactics, such as establishing nectar plants as an alternative food source and protecting against pesticides, have been suggested for the preservation of natural enemies. The preservation of substitute hosts for natural enemies has received less attention **(Cortez-Madrigal and Gutierrez-Cardenas, 2023).**

Natural biological control methods include preserving natural enemies, or artificial methods like vaccination or flooding. Buying natural enemies to supply biological control agents is frequently not required. Natural enemies are prevalent, and by creating an environment that is favourable to their survival, a grower can create production systems that draw and retain natural enemies. In order to increase the populations of advantageous species, additional natural enemies are released during flooding and vaccination. The ideal kind of control is biological control because it is sustainable, effective over the long term, and safe for the environment **(Kaur *et al.,* 2019).**

Scientists are concerned in the enhancement of natural enemies (parasites, predators, and weed feeders) through habitat management in order to control insect pests. The class of insects known as invertebrates are members of the arthropod phylum. The world's bug species are now categorised using about thirty insect orders. There are over 750,000 bug species in the hexapoda class. There are about 37 dangerous insects that are categorised as the worst kind of pests. The main agricultural pests that cause significant crop loss include the American oil beetle, aphids, blister beetles, and boll weevil, among others. According to **Oliveira *et al.* (2014),** Brazil's yearly average yield loss was 7.7% in output, resulting in a decrease of over 25 million tonnes of food, fibre, and biofuel. The economic loss was estimated to be around US$17.7 billion.

Biological pest control

According to **Eisenberg *et al.* (2001),** the phrase "biological pest control" refers to the reduction of populations of various pestiferous organisms by the use of both introduced or enhanced biological control agents and naturally occurring foes and antagonists. By keeping the detrimental impacts of pest species on crops below economically important thresholds, biological control can lessen the need for more drastic pest management techniques like the application of insecticides. The existence and preservation of a high quantity and diversity of natural enemies is essential to the biological control of agricultural pests **(Jonsson *et al.,* 2017).** On the other hand, adversarial relationships amongst foes may affect their ability to successfully suppress pests. Furthermore, because predation frequently depends on density, measurements of enemy diversity and abundance are frequently insufficient to determine if a group has the capacity to exercise effective biological control. Therefore, predator exclusion cages with standardised densities of (pest) prey are commonly used to evaluate biological control potential, as is the estimation of attack rates on sentinel prey **(Birkhofer *et al.,* 2018).**

Predators control pests

Predators are a key class of resident enemies and recent work has highlighted the effectiveness of multiple predators in suppressing populations of pests **(Tylianakis and Romo, 2010; Griffin *et al.*, 2013; Liere *et al.*, 2015)**, though their effectiveness likely depends on functional traits of both the predators (e.g. hunting mode) and the pests (e.g. life stage), species identity, crop type and environmental heterogeneity (e.g. climatic variation) **(Crowder and Jabbour, 2014; Jonsson *et al.*, 2017)**. Put another way, the impacts of predators on populations of pests might be context dependent.

Natural enemy biodiversity

Although there is debate on the contribution of predator variety to the preservation of ecosystem services like pest management and the maintenance of ecosystem function, evaluative data is starting to mount. Strong suppression to facilitative release of herbivorous arthropod prey is observed in both empirical and experimental comparisons of entomophagous arthropod and vertebrate species-rich versus species-poor assemblages **(Letourneau *et al.*, 2009).**

The biodiversity of natural enemies is a function of the number of species (species richness) that combat pests as well as the relative abundances of those species (species evenness). More enemy biodiversity may result in higher pest reduction when natural enemies occupy different, complementing feeding niches, according to recent experimental study. When natural enemy species target several pest species or stages that are present in various locations or at various times, as well as when adversaries employ various hunting techniques, complementarity may result. These advantages, however, may be diminished if predators in various predator communities murder one another, which is more likely to occur in straightforward foraging situations with a small number of prey species **(Snyder, 2019)**.

The number of species, or "richness," and the equality of relative abundances among species, or "evenness," have traditionally been considered to be the two components of biodiversity **(Snyder and Tylianakis, 2012).** Thus, evenness serves as a link between richness and abundance, which are crucial elements of biodiversity against natural enemies. Ecologists have focused the most on the advantages of species richness of the two **(Jonnson *et al.*, 2017; Greenop *et al.*, 2018).**

Methods of biological control

By suppressing the pest populations, biological control reduces the harm that pests might otherwise do. They include natural enemies including predators, parasitoids, and diseases and are crucial in reducing the concentrations of possible pests. The three main strategies for biological control are the conservation, amplification, and importation of natural enemies:

1- Importation

Natural enemy importation is another name for traditional biological control. It describes the deliberate introduction of an alien biological control agent into an invading area for the purpose of long-term establishment and pest control. Its goal is to bring the numbers of natural enemies and pests back into balance in the areas where pests have taken over without the support of their natural enemies **(Eilenberg *et al.*, 2001).**

In areas where they are not native, pests are constantly being unintentionally or purposely imported. However, these introduced species of exotic origin may turn into pests if there are no natural enemies to control their populations. In these situations, importing natural enemies can be quite successful **(Caltigirone, 1981).** Once the imported pest's nation of origin has been determined, a search may be launched to find a potential natural opponent.

After the identification of the natural enemies, their possible effect on the pest in the home country might be assessed and brought into the new nation for more research. Natural enemies are brought into the nation with permission from the relevant authorities. Initially, the newly introduced natural enemies undergo one or more generations of quarantine to prevent the unintentional introduction of unwanted species (diseases, hyperparasitoids, etc.). Additional approvals from relevant authorities are needed for field release and transportation to other states **(Bryan *et al.*, 1993).**

2- Augmentation

Augmentation is the process of manipulating natural adversaries to increase biological control's effectiveness. This can be implemented using one or both of the two broad approaches listed below:

1. mass production and sporadic colonization; alternatively, Natural enemies' genetic enhancement

The most popular ones are the first two mass production and recurring colonization. After being created in insectaries, the natural enemies are either discharged as an inoculant or as an inundated. When natural enemy populations are either absent or unable to react rapidly enough to the pest population, augmentation is employed. Because insect outbreaks can result from importation or conservation techniques, this approach cannot guarantee a lasting solution for pest reduction. One of the better examples of the inoculative release strategy is the employment of the parasitoid wasp Encarsia formosa Gahan to control populations of the whitefly, Trialeurodes vaporariorum **(Hussey and Scopes, 1985; Parrella, 1990)**.

Whiteflies are a worldwide pest of crops used in floriculture and vegetable production that are exceedingly challenging to control with pesticides. When the first whitefly is found on the crop, E. Formosa is immediately released to stop the population from growing to a harmful size. The releases must to be carried out within the framework of an integrated crop management program, keeping in mind the parasitoids' low pesticide resistance.

3- Preservation

The preservation of natural enemies is a crucial component of any biological control strategy that we implement. It is necessary to identify and further change the elements that may limit the efficiency of the natural enemy in order to increase its effectiveness. There are two methods to modify this approach:

1. lessen the elements that conflict with natural enemies or 2. Give natural adversaries the materials they require in their surroundings

A natural enemy's effectiveness can be diminished by a number of things. Applications of pesticides can either directly destroy natural enemies or have indirect effects by reducing the number of hosts or their availability in the crop. Natural enemies may suffer from cultural practices like tillage or burning crop debris because they may be killed or have their population reduced due to habitat destruction. Frequent tillage in orchards can produce dust deposits on the leaves, which can kill small predators and parasites and increase pest insects and mites.

According to a study that reveals the biological control of California red scale, Aonidiella aurantii natural (Maskell), periodic washing of citrus tree foliage may boost the efficiency of the parasitoids and achieve control **Debach and Rosen (1991).** Certain impacts of the host plant, like chemical defense that are toxic to natural enemies but best suit the pest, also lessen the effectiveness of biological control. Certain bugs possess the ability to isolate the harmful elements of their host and utilize them as a means of defense against their own adversaries. Additionally, in these situations, biological control is less effective. Certain conditions, such as the host plant's physical traits like hairy leaves, may make it more difficult for the natural enemy to locate and attack hosts.

Thus, conservation makes sure that the cropping environment meets the ecological needs of the natural enemy. Natural enemies may require access to different hosts, adult food sources, overwintering habitats, a steady supply of food, and suitable microclimates in order to be successful **(Rabb *et al.*, 1976).** According to a study by **Doutt and Nakata (1973),** the primary parasitoid of the grape leafhopper

Erythroneura elegantula is Anagrus epos Girault. In grapevines, a replacement is required during the winter months.

This host, a different leafhopper, overwinters in riparian zones, away from the vineyards, on blackberry foliage. For this reason, early parasitoid colonisation is frequently seen in the spring in vineyards close to wild blackberries. This creates the more desirable and healthful biological control. According to **Wilson *et al.* (1989),** there is an additional overwintering host present in French prune trees. Their plantation will successfully preserve A. epos because it is located upwind of the vineyards.

Benefits of biocontrol

The fact that the pest cannot or will acquire resistance extremely slowly is a significant benefit of the biological management strategy **(Weeden and Shelton, 2005)**. When attacked by a natural adversary, a target pest typically cannot establish defence systems **(Holt and Hochberg, 2005)**. Pests may evolve defence systems, such as chemical repellents and escape behaviours. Thus, "we know of no cases where previously successful biological control has failed because of selection for resistance," according to **(Van Emden and Service 2005)**.

Compared to chemical or other control methods that need to be applied repeatedly, biological control methods that have been adopted and established in a particular area can be maintained there for a longer period of time **(Kok, 1999).** Because biological control techniques only need to be used once, they are also quite affordable. Because biological control relies on self-perpetuation and self-propagation, as previously indicated, its effectiveness is higher than that of other control approaches. It is possible for a small number of biocontrol agents to reach extremely high concentrations and consistently suppress a pest over a substantial territory. Biological control is typically less expensive than chemical control when comparing the cost of deploying an agent for pest control against using pesticides. When there is no other choice, biological control has the most financial advantage. A noteworthy observation concerning the cost-effectiveness of this approach is that, while biological control may not yield as much as agrochemicals, its initial cost is typically less than that of chemical pesticides **(Reichelderfer, 1980).**

Many people agree that biological control is crucial for sustainable agricultural production, and the Millennium Ecosystem Assessment **(MEA, 2005)** lists biological control as a key regulatory function. Different "tactics" are included in biological pest control, such as classical biological control, which introduces exotic natural enemies primarily to manage invasive pests, and augmentative or inundative control, which calls for the initial or repeated release of natural enemies **(Heimpel and Mills, 2017).** On the other hand, conservation biological control makes use of localised natural enemies and use management techniques to preserve their numbers and the services they offer.

Disadvantages

We also find the disintegration of biological control programs that have been successfully executed in a number of cases. The best examples are the introduction of the cane toad to Australia and the introduction of Harmonia axyridis as a biological control agent throughout continental Europe. Australia introduced cane toads in 1935 as a biological control measure against the Greyback cane bug, which was causing damage to the sugarcane crops. Nevertheless, because the ecology and life history of cane toads were not properly taken into account prior to their introduction, the management went terribly wrong, and cane toads are now an invasive pest in Australia. Comparably, the harlequin ladybird, or H. axyridis (Coleoptera: Coccinellidae), was brought to continental Europe in 2004 **(Majerus *et al.*, 2006)** from Sible Hedingham, Essex, England, to act as a biological control agent against aphids. Due to their superior dispersal skills and certain anthropogenic activities, the individuals spread and became invasive from Europe to Britain **(Brown *et al.*, 2008 and Jeffries *et al.*, 2013)**.

Growers' intolerance with traditional insecticides is another significant drawback. Chemical treatment is one of the quick fixes for any pest population, and growers are known for their lack of patience **(Kok, 1999).** Because biological management is a difficult process that takes a lot of time and patience to produce long-term effects, producers prefer the powerful pesticides. The constraint of biological control over subsequent pesticide usage is stated by **Van Emden and Service, (2004).** "It is obviously difficult to continue using insecticides against other pests on the same crop or other disease vectors in the same area where biological control agents are being used against one pest." This could render the application of biological control unfeasible.

Conclusion

An eco-friendly and developing method of pest management is biocontrol. It doesn't leave any chemical leftovers that could be dangerous to people or other living things. Natural enemy importation, amplification, and conservation are the three main strategies for biological control. The fundamental techniques of these systems are always evolving and being adjusted to satisfy the changing needs of pest control. The efficacy of biological control agents has grown due to genetic advancements of natural enemies and modifications and advancements in rearing and application strategies. Furthermore, the demand for study on natural enemy conservation is changing as a result of the application of new ecological concepts. It will take ongoing strategy and application modification and refining for its full potential to be implemented successfully. The growing organic market's demands for biological control combined with the additional load from consumers create favourable conditions for the development of biological control agents in agriculture in the future.

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لمحة موجزة عن المكافحة البيولوجية

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الملخص العربي

الآفات مسؤولة بشكل كبير عن خسائر فادحة في المحاصيل وانخفاض الإمدادات الغذائية، وتدني جودة المنتجات الزراعية، والصعوبات الاقتصادية التي يواجهها المزارعون والمصنعون. بشكل عام، يتم تطبيق طرق التحكم الكيميائي من أجل مكافحتها والتي لا تكون دائمًا اقتصادية أو فعالة وقد ترتبط بمخاطر غير مرغوب فيها على الصحة والسلامة والبيئة. ومع ذلك، لمواجهة التحدي المتمثل في تغذية الأعداد المتزايدة من السكان، فمن الضروري وجود طرق فعالة واقتصادية وصديقة للبيئة لمكافحة الأمراض. في هذا الصدد، قد تكون المكافحة البيولوجية وسيلة فعالة لتقليل أو تخفيف الآفات وآثارها من خلال استخدام الأعداء الطبيعيين. المكافحة البيولوجية هي عملية سليمة بيئيًا تتضمن استخدام الكائنات الحية الدقيقة المفيدة للسيطرة على مسببات الأمراض النباتية والأمراض التي تسببها. تلخص هذه المراجعة فعالية ومزايا وسلامة استخدام العوامل البيولوجية لقمع ومكافحة الأضرار التي تلحق بالمحاصيل بسبب الحشرات. لقد ثبت عمومًا أن المكافحة الحيوية آمنة للنباتات والحيوانات والبشر والبيئة. وهذا يتناقض بشكل صارخ مع المبيدات الحشرية الكيميائية المستخدمة على نطاق واسع والتي غالبًا ما تؤدي إلى تلوث بيئي يسبب ضررًا للإنسان والبيئة. يواصل مصنعو المكافحة الحيوية تطوير بروتوكولات جديدة لتقييم سلامة العوامل ونشر وقياس نجاح العلاج. تعمل المنظمات الحكومية والتصنيعية على تطوير لوائح لضمان الاستخدام الآمن والمناسب للمكافحة الحيوية. إن فوائد أنظمة المكافحة البيولوجية تدفع إلى الاعتماد المتزايد على التكنولوجيا. تعد حماية التنوع البيولوجي وارتفاع نسبة الفوائد إلى التكلفة من الأسباب الواضحة لتشجيع استخدام منصات المكافحة الحيوية. وسوف يتطلب الأمر تثقيف وتوعية عامة الناس والمشاركين في الزراعة لقبول هذه الممارسات الزراعية البديلة.