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Review Article

Biorational Insecticides and Agro-Ecological Options in Pest Management: Providing Solutions to Pesticide Contamination of Vegetable in Ghana

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Abstract

The goal of this review was to identify potential long-term pest management strategies for reducing vegetable contamination in Ghana. Pesticide contaminations are easily transmitted through the consumption of vegetables. The majority of pesticide-related health studies have focused on people who are exposed as a result of their occupation, such as farmworkers and pesticide applicators. Vegetables are susceptible to a variety of insect pests and diseases, which limit their production in Ghana. Accordingly, a wide range of synthetic insecticides are continuously being used for their management. This type of strategy is seriously increasing vegetable contamination, which is endangering the health of consumers in Ghana. To alleviate the alarming situation, the development of potential sustainable pest management strategies such as; biorational pesticides and agro-ecological strategies should be encouraged. Furthermore, the illegal use of prohibited chemicals such as DDTs, as well as their persistent nature, is critical and must be treated with the greatest concern it deserves.

Keywords: Vegetables Contamination; Pesticides; Biorational Insecticides; Integrated Pest Management; Agro-Ecological Strategy

Introduction

Nutrition is a major concern around the world, despite the persistent threat to national food security. A significant number of people are starving, and two-thirds of those identified are victims of hidden malnutrition [1]. Vegetable production contributes significantly to food and nutritional security, as well as to individual well-being. Traditional vegetables in Africa are considered essential due to their adaptation to a year-round production season. In Ghana, vegetable production is an important source of income and it helps to reduce unemployment. Most rural and urban areas supply fresh produce to the market all year. Other local farmers grow vegetables on the outskirts of towns and in backyard gardens for subsistence [2]. As a result, it contributes to food, income, and nutritional security in many African countries including Ghana. Important vegetable crops such as chillies and okra are exported from Ghana to Switzerland, Germany, and many other countries, boosting foreign exchange [3]. Chilli exports have ranged between 26,000 and 41,000 MT per year over the last five years, with equivalent foreign exchange ranging from US$18.2 to US$28.7 million [3].

Pesticide infections are easily transmitted through vegetable contamination, and most studies on the health effects of pesticides have focused on people who are exposed as a result of their occupation, such as farmworkers and pesticide applicators. Vegetable production is hampered by major insect pests, necessitating an urgent and appropriate pest management strategy in Ghana. This has led to an increase in the use of synthetic pesticides for pest control, primarily in horticulture and high-value vegetables [4]. According to the World Health Organization (WHO), developing countries account for 20% of global pesticide use, posing a risk to human health and the environment [5]. Ghana was barred from exporting vegetable produce to some EU countries a few years ago due to pesticide contamination [8]. Following the ban, the Ghanaian government, in collaboration with the private sector and some NGOs, enacted a number of measures to ensure that farmers producing vegetables for export adhere to best practices. This development resulted in the ban being lifted in 2012 [6]. Unfortunately, the quality of vegetable produce consumed in the country is low because farmers do not use pest management strategies to protect local consumers. The goal of this review is to identify potential long-term pest management strategies for reducing vegetable contamination in Ghana.

Synthetic pesticides application and its potential threat on food crops

Some pesticide residues can be retained by food crops for an extended period of time. Spraying too close to maturity or harvest may cause pesticide residues to accumulate until the consumer consumes the produce [7]. Generally, about 87% of Ghanaian vegetable farmers relies on synthetic pesticides for insect pest's management in their farms [8] (Table 1). Farmers apply the same pesticides to all vegetables and ignore pre-harvest intervals [9]. The farmers may spray pesticides near harvest time in order to sell 'appealing' vegetables. This practice puts the health of consumers at risk. An earlier study reported that boiling of produce can reduce pesticide residues by 20-60%. As a result, the assumption that proper cleaning and boiling of vegetables can remove pesticide residues is questionable [6]. Pesticide residues above tolerance limits have been found in boiled vegetables and consumption of such vegetables significantly threaten public health [10].

Trade Name	Active Ingredient
Buffalo	Acetamiprid
Golan	Acetamiprid
Conpyrifos	Chlorpyrifos ethyl
dursban	Chlorpyrifos ethyl
Termicot	Chlorpyrifos ethyl
Polythrine C	Cypermethrin
Control	Emamectin benzoate
Consider	Imidacloprid
Clear	Lambda cyhalothrin
Karate	Lambda cyhalothrin
Lambda	Lambda cyhalothrin
K-optimal	Lambda cyhalothrin
Bypel	Perisrapae granulosis virus
Actellic	Pirimiphos-methyl
Actara	Thiamethoxam
Furadan	Carbofuran

Table 1: Common pesticides used in vegetable cultivation in Ghana.

The level of heavy metals contamination in vegetable produce in Ghana

Farming activities such as chemical pest and weed control, irrigation, fertilizer application, and nomadism along the reservoir can affect the quality of the water, posing a health risk to humans, livestock, and other aquatic life. Furthermore, the reservoir water is constantly used for irrigation of leafy and fruit vegetables, among other food types, making it susceptible to bioaccumulation of agrochemicals and other organic matter used in farming along the reservoir [11]. The level of heavy metal contamination of the food item is one of the most important aspects of food quality assurance [11]. Heavy metals can be easily absorbed by vegetables. Prolonged consumption of heavy metal-contaminated vegetables may result in kidney and liver problems. The fitness risk is determined by the amount of vegetables consumed as well as the consumer's weight. Long-term consumption of vegetables with low-concentration of heavy metals may have a negative impact on consumers' health [12]. This necessitates the performance of diagnostics in order to support the enforcement of rules governing water source contamination which is caused by frequent use of chemicals in developing countries such as Ghana.

Biorational insecticides approaches to pest management

A report has indicated that biopesticides account for less than 1% of the global insecticide market [13]. Currently, the US Environmental Protection Agency has registered over 800 insecticides in various products. Chemical insecticides, on the other hand, account for nearly 99% of the market, and their environmental impact is a major concern. The biorational pesticide is non-toxic to the environment and only toxic to the target organism. Surprisingly, most farmers around the world use harmful chemical pesticides that contaminate food crops, particularly vegetables. Biopesticides are frequently overlooked due to a variety of factors such as unpredictable outcomes, collegial pricing in comparison to other pesticides, incorrect formulations, and pest restrictions. Nonetheless, the anticipated benefits of biorational pesticides have recently prompted several scientific studies.

In this context, several biological products have been approved. The Environmental Protection Agency of US has developed pesticide regulations to replace chemical pesticides in order to encourage the commercialization of natural or biorational pesticides. More than 800 biorational pesticides and 190 active ingredients are registered in the United States. Biorational pesticides are classified by the EPA into three types: microbial pesticides, plant pesticides, and biochemical pesticides [14]. Biopesticides are less harmful than conventional pesticides but effective for pest management when formulated and used correctly, thus they are highly recommended for integrated pest management [15]. As a result, biorational pesticide application has the potential to significantly reduce chemical insecticide use while maintaining high crop yields and reducing contamination. Another distinguishing feature is the focus on target insect pests and other related organisms, as opposed to conventional pesticides, which can harm diverse organisms including birds, insects, and mammals. Furthermore, because multiple toxins, such as Bt, are used to kill the insect in many cases, the possibility of developing resistance by the pest is greatly reduced, even with widespread use over time [16].

Microbial pesticides

The active ingredients of micro pesticides are microorganisms, such as bacterium, fungus, virus, or protozoan. These pesticides contain diverse active ingredients that are lethal to specific target pest. Subspecies *Bt* is the most widely utilized among the microbial pesticides and each bacterium is diverse mix of proteins that adversely inhibit insect pests performance. The Bt strains are known to control moth larvae found on plants, other strains are specific for larvae of flies and mosquitoes. The target insect species are determined by whether the particular *Bt* produces a protein that could influence the insect performance [17].

Bacteria

Insecticide bacterium *Bt* is a soil bacterium which forms crystalline protein inclusion during sporulation [17]. In this process, the bacterium produces insecticidal crystal protein (d -endotoxin), which is fixed on bacterial plasmids . Among the nine different toxins that have been introduced in *Bt* strains, d -endotoxin is widely used commercially for the management of insect pests [18]. The toxins effects on specificities is greatly dependant on its various insect receptors such as phospholipids, phosphatidylcholine, and sphingomyelin. This biorational pesticide is originally commercialized and used to protect crops against pests. Presently, few or more of this products are used in USA, Argentina, Mexico, China, Canada, France, Australia, Spain, Ukraine, Portugal, and Africa , thus, indicates about 1-2% of the global insecticide market. Its lethal effects are reported on tobacco budworm, pink bollworm, Colorado potato beetle, cotton bollworm, corn borer, among others. This has significantly reduced the use of synthetic pesticides for pest management in most areas [19]. For instance, in China, the widely use of *Bt* pesticides has reduced the use of organophosphate and organochlorine insecticides form 20 to 7/ha/season [20]. In Ghana, *Bt* derived products are used for the management of fall army worm in maize and other vegetable pests. This potentially reduced chemical insecticides treatments for target pests, improved crop yield, and reduced contamination of farm produce. Unlike in other countries, *Bt* derived products have not been the first choice for vegetable pest management in Ghana, though application of this product showed excellent control of insect pest while sparing the activities of non-target organisms.

Viruses

Several diverse viruses including baculovirus have exhibited their potential for insect pest control, especially, Lepidoptera and Diptera. They are commercially marketed because they are safe to vertebrates, plants, and non-target organisms [21]. In 1971, *Helicoverpa* (*Heliothis*) *zea* was registered as the first virus pesticide under the tradenames Viron/H and later Elcar. This virus exhibited significant lethal effects of the tobacco budworm (*Heliothis virescens*), corn earworm (*Heliothis zea*) and *Heliothis armigera* on cotton, fruits and vegetables. Like other biorational insecticides, the efficacy of baculovirus pesticides is high due to its narrow spectrum of biological activity, slow mode of action and photolability. Baculovirus control insects by inducing systemic or cell-to-cell spread of the virus within an infected insect. This process affects host larva and reduces developmental period, feeding, and mobility and intensify exposure to predation [22]. Post larval effects may include lower pupal and adult weights, as well as reduced reproductive capacity and longevity. Infected larvae usually climb to the upper parts of the plants, dying in 5-8 days although cessation of feeding may occur in 2-4 days depending on biotic and abiotic factors. Baculoviruses control diseased and dead larvae that serves as inoculums for virus transmission that may occur by arthropods on plants, predators, or rain [23]. In Ghana, farmers predominantly utilize synthetic pesticides than baculoviruses. This is due to the high cost of baculoviruses products, which may possibly increase input cost of vegetable producers. Consequently, wide range of synthetic pesticides exposes vegetable produce to pesticide residues contamination.

Fungi

Fungi microbial pesticides are one of the major classes of biorational pesticides word-wide. Several fungi are referred to as entomopathogenic fungi, due to their pathogenic effects on insect pests. Most of the entomopathogenic fungi either belong to the class Entomophthorales or Hyphoymycetes. Species within Entomophthorales or Hyphoymycetes vary according to insect host, infection levels, germination rates and optimum temperature of action [24]. Species in these classes affects several insect order and other major pests in vegetables by synthesizing host plants defence mechanisms and influences tissue colonization with little or no use of toxins. Others attack insect pests through direct penetration of spiroacular openings in the insect's cuticle. Even though about 750 fungal species are known to infect insects, only few fungi pesticide products have been commercialized in USA, Europe, Latin America, and China. The most notable mycoinsecticides in use are: *Beauveria bassiana*, *Beauveria brongniari*, *Metarhizium anisopliae*, and *Metarhizium flavoviride*. Relatively, *B. bassiana* is considered the most marketable in the US, Europe, Russia, South America and also in China [25]. *B. bassiana* is registered is China for the control of the pine moth *Dendrolimus* spp, *B. bassiana* strain Bb-147 in Europe for control of the European corn borer *Ostrinia nubilalis,* and the Asiatic corn borer *Ostrinia furnacalis*. *B. bassiana* strain GHA, in contrast, is registered in the US for control of the whitefly, thrips, aphids and mealybugs. *B. bassiana* strain ATCC 74040 is registered against many soft-bodied insects of the orders Homoptera, Heteroptera and Coleoptera. *B. brongniari* is Russia [26]. These developed countries largely use enthomopathogenic fungi for the pest management due its minimal effects on non-target pest, and it also poses no risk to farm operators and consumers, compared with most chemical insecticides. Like others, fungi microbial pesticides are not largely utilized by farmers in Ghana, thus commercializing it is paramount for crop production, especially vegetables.

Botanical insecticides

Plants and animal derivatives are naturally occurring chemicals that are extensively used as agricultural insecticides for centuries. Some of the widely used botanicals include; Pyrethrum from *Chrysanthemum cinerariifolium* Vis. (Compositae), rotenone from *Lonchocarpus nicou* or *Derris elliptica* (Leguminosae), and nicotine from *Nicotiana tabacum* (Solanaceae) [27]. The development of synthetic insecticides such as organochlorinated, organophosphate, carbamate drastically reduced the use of botanical insecticides due to their efficacy, lower cost, and longer lasting properties. Presently, major commercial botanicals used for insect pest management includes; pyrethrum, rotenone, neem and essential oils. In Ghana, derived from *Azadirachta indica*, neem-based insecticides contain azadirachtin, a complex tetranortriterpene, is the most commercialised. Neem extract is extensively used due to its several beneficial effects on insect pests [28] A large number of maize producers comprehensively use neem seed oil and neem leaf extract for the management of fall army worm.

Biorational pesticides use in Ghana

In 2017, the Government of Ghana recognised the risks posed by non-biorational insecticides for the urgent management of fall army worm. The use of non-biorational insecticides to manage the infestation showed long-term consequences for people, animals, environment and consumers [29]. To supplement the Government's emergency stock of insecticides, farmers were buying both regulated and unregulated chemicals to control the pest; many of which had not been proven tested and found effective against fall army worm. Inadequate education on appropriate use of pesticides, and flexible implementation of regulatory regime resulted in dosage, frequency, and timing of application. Moreover, most pests developed resistance to the active ingredients in the chemicals applied. The attendant health hazards to humans directly involved in the spraying of crops and indirectly through compromised food safety were also a concern. Accordingly, the National Learning Alliance (NLA) and Centre for Agriculture and Bioscience International (CABI) supported the Ministry of Food and Agriculture (MoFA) to implement policy to regulate the use of chemicals in managing pests. This intervention contributed to a change in attention away from non-biorational management strategy in the Government's present pest management plan. There were indication of farmers using bio-rationals that are less harmful to consumers and the environment. Biorational pesticides in Ghana increased from three in 2017 and to five in 2018/2019. During the same period, the purchases of bio-rational pesticides increased in 2018 and 2019. For instance, the quantity of *Bacillus thuringiensis* (55%) + Monosultap (45%) and Maltodextrin purchased increased in 2018 and in 2019 [29]. In Ghana, *Bacillus thuringiensis* (Bt) is the most widely used bio-rational pesticide [30]. There has been a major switch from non-biorational control to bio-rational control. This is due to the government's fall army worm control plan which states that "in the long term, only biological control agents, microbial insecticides and botanicals/organic products will be used to manage FAW in Ghana [29]." This suggest that the Government's effort to implement policy to regulate the use of chemicals is only focussed on fall army worm on maize. Accordingly, most vegetable producers continuously use chemical pesticides for pest management. Therefore, some vegetable producers shift their focus from chemical control to biorational and other cultural management such as scouting, crop monitoring and the use of resistant varieties as strategies towards sustainable pest management in Ghana.

Agro-ecological approaches to pest management

Pest management practices have been used in and around farmers' fields since agriculture began [31]. Soil amendments that increase plant vigour to withstand multiple stressors, improved biodiversity that increases natural enemies, and specific management activities aimed at preventing or mitigating the effects of outbreaks are all part of agro-ecological pest management strategies. Many interventions are already aligned with other concepts of sustainable land management, such as climate smart agriculture. Crop rotations, intercropping, and crop residue mulching, for example, can be implemented at the field scale, allowing diverse crop margins and in-field diversity to develop, improving plant diversity on farmers' fields through tree and shrub planting, and increasing landscape on agricultural fields [32]. Insect diversity has increased significantly as plant diversity has increased. Diversity is essential because different natural enemies are more effective at managing different pests at different developmental stages and seasons. Nonetheless, pest control can be improved through biodiversity management at multiple scales [31].

Particular intercropping strategies could be used for pest management, as it reduces larvae movement among different host plants, by reducing oviposition on crop plants, primarily through the emission of volatiles that directly repel egg-laying females or provide olfactory camouflage. Many natural enemies react to plant volatiles released when a plant is damaged by a herbivore, but the strength of these signals is often greatly reduced in modern crop varieties [33]. Some natural enemies, on the other hand, may respond to semiochemicals released by carefully chosen companion plants. Weeds could be used for pest management by providing habitat for natural enemies where their growth does not impede crop growth [34]. Field margins can be improved by selectively removing some plants and planting others [58]. Open flower plants and trees provide nectar for parasitoids and habitats for natural enemies that are generalists. Ants, which are important insect predators in natural ecosystems, are often overlooked in pest management because their role in pest management is not well understood. Social wasps are also important in the management of moth larvae, and their contribution to agriculture is underappreciated [35]. Beneficial species may benefit from land-scape management practices that create barriers to crop pest movement. Landscape features, on the other hand, can influence the outcome of natural enemy interactions [35]. Some insect pests are preyed upon by insectivorous birds, whose effectiveness is dependent on the size of the tree or shrub cover. Natural enemy nesting sites can even be provided as part of pest control management; Huang and Yang [36].

The agro-ecological pest management strategy entails incorporating complementary interventions into the farming system at different spatial scales. The majority of measures, such as those that improve soil health or diversify farm produce, serve multiple purposes. As a result, the method capitalizes on natural interactions within crop fields. Furthermore, precise procedures usually improve pest management for a wide range of pest species. The approach's discontinuities also provide farmers with options, allowing them to integrate methods based on the specific constraints they face. Farmers will need a variety of options if agro-ecological pest management approaches are to be scaled up in SSA [37]. On the other hand, it appears to overburden women and young children. Finally, while agro-dealers play an important role in providing inputs such as seeds or seedlings for intercrops and field margin plants, they may not support the use of agro-ecological strategies as an alternative to chemical pesticides.

Agro-ecological management

Fertiliser application

Plant vigour is considered an important physiological trait to withstand insect pests. Notwithstanding, incorrect application of inorganic fertilisers could improve insect herbivore growth and development [38]. It is reported that the application of inorganic fertilizer increase the performance of aphids compared with organic fertilizers. Inappropriate application of fertilizer increases nitrogen concentration, which support osmoregulation mechanism of sup-sucking insects. In contrast, high organic matter and active soil biology showed least population growth of insect pest and high yield, whereas high population abundance occurred on low organic matter soils. Regardless the presence of pest, inorganic fertilizer application could improve plant growth and increase yields [39]. Most small hold farmers in Ghana complains on increase of weed pressure and weeds management challenges resulting from fertilizer application. However, linking pest control benefits to sustainable soil fertility management help to overcome impairments to adoption. Therefore, recommending sustainable soil fertility management approaches could reduce the use of chemical pesticides for pest management. This would be incorporated with the use of nitrogen fixing cover crops, crop rotation, inter-cropping, composted livestock manure, alongside the application of inorganic fertilisers [40].

Habitat diversification at farm scale

Several research reported that diversification of habitat increase the population of natural enemies for pest management [41]. Environmental successions with high habitat diversity improved abundance of natural enemies on crop field. Higher parasitoid diversity and parasitism rates were found in areas with higher habitat diversification in maize fields. Predators such as ants, social wasps and spiders were also abundance in unsprayed fields than sprayed fields. This was due to lower plant diversity in the sprayed fields [42]. Habitat diversity ecological principle obviously improve field efficiency of natural enemies in managing insect pest. In general, intercropping is used as an efficient farming system to modify the microenvironment of insect pests in Ghana. It changes the environment by increasing or changing the crop pattern in the ecosystem [43]. Intercropping increases crop diversity, alters insect habitats, and prevents insects from identifying host plants. Crop mixtures divert insect pests' attention by increasing the complexity of plants that provide a less favourable environment for some insect pests. Several studies have shown that insect pests settle on crops only when host factors such as visual stimulus, taste, and smell are satisfied, resulting in a reduction in the rate of pest population development, net damage, and infestation [43]. Most Ghanaian farmers' intercrop legumes with cereals or grains and tuber crops. For instance, intercropping maize, sorghum, millet, and cassava reduced pest damage, increased yield, and maximized profit. Intercropping cereal and cowpea reduced pest infestation while increasing yield. Cowpea/sorghum intercropping effectively reduced the population of aphids and thrips, whereas cowpea/green grain intercropping was effective against legume pod borers and pod sucking bugs [42]. However, intercropping legumes or other crops with vegetables to control vegetable pests is not common among Ghanaian farmers.

Agroforestry

The presence of trees and shrubs form important component of agro-ecological pest management, as they increase structural diversity. The presence of three and shrubs improves the abundance of birds and bats that act as natural enemies to control insect pests [44]. Several studies show that freetailed bats feed up to 4 billion moths each night and their rate of consumption correlate positively with the migration of insect pests. Like bats, birds are also reported to feed on several species of insect pests and are more abundant in diverse fields margin habit [44]. In sub Saharan Africa, several development agencies promote the use of trees, such as *Gliricidia sepium* (Jacq.) *Kunth ex Walp*, *Tephrosia volgelii* Hook, and *Faidherbia albida* (Delile) A. Chev, to improve pest management. In northern Ghana, trees and shrubs have shown potential control of fall army worm and other pest. Moreover, leaves and seeds of neem trees which contain insecticidal properties are widely used as extracts for pest management [45]. The use of tree and shrubs is being widely promoted within the concept of climate smart agriculture and hence there is ample opportunity to incorporate this agro-ecological technique in vegetable production in management of vegetable pests.

Early planting

Planting early after first rain generally improves plant vigour by providing conducive conditions for plants. At early season, pest infestation is reduced, however, early planting is also associated with increased risk of crop failure, as the early rains may be erratic. In Ghana, most smallholder farmers plant their crops early, whiles others deliberately delay planting but later uses early maturing varieties [46]. Farmers are presently educated to wait for the first cropping rains of 30-50mm that fall in 2-3 successive days. This usually provide sufficient soil moisture for crop development, particularly if that is not the first rainfall occurrence, and reduces the possibility of crop failure. Staggered planting also helps farmers disaggregate labour peaks and hence potentially benefits women and children who are frequently responsible for planting and concerned of the vegetable crops. Early planting as an agro-ecological management technique is reported to improve ecological management to minimize indiscriminate application of chemical pesticides.

Recent deaths from pesticide contamination in Ghana

The exact number of deaths due to pesticide contamination in Ghana is not known. However, the loss of 15 persons that occurred in the late 2010 in the Upper East region of Ghana was suspected to be caused by pesticide poisoning [47]. Most of these deaths transpired as a result of application of pesticides, poor storage of pesticides, and consumption of agricultural contaminated produce. For instance, in December 2010, 12 people were reported dead after eating food contaminated with pesticides [48]. These people reported food poisoning due to synthetic pesticides defined symptoms including dizziness, stomach problems, and headaches. It is reported that some natural deaths among Ghanaians might be associated with the use of synthetic pesticides, as pesticide poisonings are difficult to diagnose [50]. When humans and animals are exposed to large dosage of synthetic pesticides the toxic effects are fairly easy to diagnose, however, long-term exposure to low doses are hard to diagnose. Most importantly, the effects of regular consumptions of pesticide residues in contaminated food are difficult to diagnose and quantify. Therefore, advocating for the use of biorational and agro-ecological management for pest control is vital in crop production [50]. Assessment of dietary exposures to vegetables contaminants in Ghana showed that estimated exposures were as a result of consumption of pesticide contaminated vegetables. This assessment indicated higher exposure to contaminants that occur from one food source, vegetables [48]. Strategically, public education to educate farmers in Ghana on the health implication in the use of synthetic pesticides in vegetable farming.

Conclusion

The need for increased food crop production to feed the growing world population cannot be overemphasized. Unfortunately, the adverse effects of insect pests on vegetable crops has for decades remained one of the major challenges against vegetable production. As a result, a wide range of synthetic insecticides are constantly being used to manage them. This type of strategy is significantly increasing vegetable contamination, putting Ghanaian consumers' health at risk. Contrary, natural products have had a significant positive impact on crop protection over the years. Undoubtedly, several compounds have entered the Ghanaian market and remained for an extended period of time. Important regulatory policies in Africa will facilitate the process of insect pest management, which will aid in pesticide application monitoring. To address this worrying situation, potential sustainable insect pests management strategies such as the use of biorational pesticides and agro-ecological systems should be encouraged among vegetable farmers. Furthermore, the illegal use of prohibited chemicals like DDTs, as well as their persistent nature, should be checked with the greatest efforts required addressed the problem.

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