Integrated Pest Management (IPM) for Smallholder Vegetable Farmers under Tropical conditions

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Abstract

1. Problem analysis

Yield and quality loss caused by pests is one of the main constraints to vegetable production. Depending on crop, production system, region and level of management, such loss has been estimated from 15 to 85% on average (Oerke 2006). High losses are often suffered by smallholder vegetable farmers under tropical conditions, where total crop abandonment due to pests is not uncommon because of high pest pressure and inadequate management.

Since the 1970's, the use of synthetic chemical pesticides continues to be the main strategy for pest management, achieving appropriate pest control in many production systems. The use of pesticides is, however, increasingly being questioned as more and more evidence documents the hidden and external environmental and health hazard costs of pesticide use, which has led to a recurring controversy over use and abuse of pesticides (Bourguet & Guillemaud 2016). This development is currently evolving while pesticide use by smallholder farmers in the tropics is increasing dramatically (FAOSTAT 2018; Loha et al. 2018).

In the UN, integrated pest management (IPM) is being promoted under the sustainable development goals (SDG) agreed upon by member states to ensure environmental sustainability. The UN and the FAO, thus, recommends IPM as a strategy for mitigating the negative effects of increased pesticide use in developing countries (FAO 2003). In the EU and the Netherlands, IPM is imposed in member states by political directives (EC 2020). IPM is universally described as "The careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agroecosystems and encourages natural pest control mechanisms".

The institutional vision of the Crop Protection team at WUR Field Crops states: "Our work focuses on pest management solutions within a crop production systems approach integrating the following building blocks: Monitoring and warning techniques, agricultural practices to improve crop resilience, biological control, and a well-considered use of chemical control. The focus is on a system approach for Integrated Pest Management (IPM) whereby chemical agents are used more efficiently and their use is reduced. The team's ambition is to further develop this integrated systems approach and, in the longer term, contribute to the transition to nature-inclusive and more biodiverse plant production systems". As part of the Field Crops business unit, a common vision would strengthen Team International's institutional anchorage. Team International could follow this vision in our training programs, considering of course the reality of the farmers and trainers we are working with.

The use of pesticides has increased exponentially in many developing countries in recent decades (FAOSTAT 2018). A development that is largely taking place under conditions of smallholder vegetable farmers that lack knowledge about pesticide management, especially about safety and the risk to health and the environment and alternative IPM options in general. Pesticides are often considered a quick, easy, and inexpensive solution for controlling pests. A view that has been promoted by pesticide sales people, the main source of information for the majority of farmers in developing countries (Loha et al. 2018; Nchanji et al. 2018)
Actions following a saying such as "if a little is good, a lot more will be better" is a common misconception that is causing widespread health and environmental problems. A common misunderstanding developed among farmers from their easy access to cheap pesticides.

The reality concerning access to and use of pesticides, as well as the related regulations, for smallholder farmers under tropical conditions is distinct from that of European farmers. To mention a few aspects, enforcement of regulation of use of pesticides is commonly not practiced, application and personal protection equipment (PPE) is expensive or not accessible, hundreds of commercial products are often registered with the same active ingredients and sold without control of quality, control of sales or recollection of contaminated waste. Furthermore, it is not uncommon to see counterfeit and hazard category I and II pesticides products banned in other countries end up in the production systems of developing countries (Nchanji et al. 2018; Wilson and Tisdell 2001).

In this context there is a strong need to convey the message that prevention of negative effects and promotion of health are worthwhile investments for smallholder farmers and their families. IPM is an integrated approach that aims at just this, to deliver management practices that support efficient use of pesticides to reduce the use when not necessary to minimize human and environmental exposure to pesticides. Many cases show that the longer term disadvantages will outweigh the benefits in the following decade, although the immediate return from investment in chemicals may be high, because of resistance development in the pest populations and secondary pest insurgence following the destruction of natural enemy populations. This is in addition to the overwhelming evidence that some of these chemicals pose a potential risk to humans and other non-target organisms in the environment.

The purchase costs of pesticides and the cost of application are only a small part of the wide-ranging costs associated with pesticide use. A comprehensive evaluation of the costs of pesticide use includes the wide reaching costs associated with their impact on health and the environment, so called external costs which are often paid by a third party: regulatory costs, human health costs, environmental costs and defensive expenditures. The internal costs of pesticide use are the costs, to the farmer, of pesticide use within the agricultural production process. These costs are described as "internal" because they determine the price of the final product, i.e. they are internal to the market (Bourguet and Guillemaud 2016; Wilson and Tisdell 2001).

Considering the above described concerns about efficient and environmentally sustainable crop protection, this report describes major IPM components and their potential for smallholder vegetable farmers under tropical conditions: prevention, monitoring, action thresholds, cultural, biological and chemical control. Recommendations on how to maximize crop protection strategies are presented. IPM, which again should be part of an integrated crop and farm management strategy is knowledge intensive. To facilitate promotion and implementation the study focuses on the least complex recommendations that can be applied by smallholder farmers in the short to medium term following training events and which are considered to give farmers significant economic benefit.

2. Vegetable IPM approaches in the tropics

2.1 Prevention

Prevention is a key component of IPM as it reduces or even eliminates the need for implementation of control measures in later stages of crop development. Measures that prevent pests from causing economic loss and which are implemented before or at planting are listed in the following section. After that, section 2.2 presents cultural pest control practices implemented after planting.

2.1.1 Land selection, preparation and planting:

Sanitation of selected crop fields by removing or burning plant debris that may contain pests is a good IPM practice for preventing mainly pathogens, be it in seedbeds, in nurseries or main fields.

Deep ploughing which kills various stages of pests.

Solarization of soils for disinfestation from pathogens, weed seeds and nematodes is effective for smallholder farmers in nurseries and in the open field. It is also used to disinfest soil medium to be used in combination with other potting media (e.g. peat moss, cocoa peat) in nurseries.

Adjustment of the time of planting and harvesting to escape peak season of pest attack. The rainy season is often favourable to pathogen attack as many pathogens flourish under humid conditions. The dry season is typically favourable to insect attack as insects are washed away in the rainy season. For instance, aphid infestations and other arthropods can be reduced by shifting the planting time, and tomato late blight disease pressure can be reduced by avoiding the most humid period of the year.

Rotation of crops with non-host crops is a key component of IPM practices. It helps to reduce the incidence of soil borne pests, mainly pathogens, but also arthropod pest populations. The rotation must be done with non-host species of other crop families. For example, it is important not to rotate tomato with other members of the *Solanaceae* family, such as eggplant, potato, bell and chili peppers. False hosts or trap hosts can not only starve pests out from lack of a plant host to live off, but will make certain adult pests reproduce, i.e. lay eggs and leave their young stages to hatch with no host plant, which will eliminate such pests that otherwise could lay to rest and survive in the soil for many years.

Inter-cropping or species/variety mixture cropping reduce pest pressure. All crops offer different preference to diverse pests. Crop species are compatible with selected pathogens with which they can develop disease and within a crop species some varieties are more susceptible than others (i.e. varietal resistance or pest preference levels). Some crops act as repellents or attractants, thus affecting pest populations and potentially keeping pests away from crops resulting in reduction of pest incidence. Such systems are called "Push–pull control strategies" for insect pests. The push–pull effect is established by repelling the insect pest from the crop ("push") and attracting them into trap crops ("pull"). This system has been successful for control of maize and sorghum stem borers using napier or sudan grass as the "pull" planted around cereal crops and leguminous *Desmodium* plants planted in between the rows of maize or sorghum as the "push". An IPM strategy that is very popular with smallholder maize growers in Africa (Khan et al. 2014).

Trap crops, which are preferred more by a pest species, can be grown on the borders of fields to attract and trap pests. By growing such crops pest populations are lured away from the crop where they can also either be killed by using pesticides or by natural enemies.

Crop diversity does not create an arthropod or pathogen favourable plant environment as opposed to mono-culture, and is commonly used in low-input agriculture as an important strategy of pest prevention. Every crop has beneficial companion crops that can help in the growth by attracting beneficial insects and repelling pests, as well as providing nutrients, shade, or support. For example, alliums inter-planted with carrots confuse onion and carrot flies.

Proper row and plant spacing will produce more pest resistant plants and less pest attack. Adequate spacing can improve aeration and restrict a pest favourable microclimate in the crop foliage and improve individual plant vigour from reduced competition.

2.1.2 Healthy planting material:

The use of pest resistant crop varieties is a key component of IPM practices. The use of disease resistant or tolerant crop varieties can reduce disease pressure dramatically and often to levels that reduce the need for fungicide to less than half of what is needed in susceptible varieties or to levels that do not require further management. Some crop varieties are also significantly more attractive to arthropod pests than other varieties.

Healthy planting material with low levels of pathogens is another key component of IPM. Seed and transplanting material should be sourced from certified seed vendors or known trusted sources of clean planting material. Seeds can be treated with fungicide or bio-pesticides before sowing for seedborne disease control. Nursery plants can be sprayed/dipped in copper fungicide/ bio pesticide solutions to protect the plants from soil borne diseases.

Selection of early and high yielding varieties can help to avoid periods during the cropping season of high disease pressure and produce acceptable yields before pest attacks become severe. By reducing the cropping period through fast maturing varieties the number of pesticide applications over time can be reduced in a similar ratio as the period for pest protection is similarly shortened.

2.2 Cultural control

Cultural control involves agricultural practices that either destroy pest populations or prevent them from causing economic loss. Agricultural practices implemented during crop growth and after planting are listed below.

Proper water management as the high moisture in soil for prolonged period is conducive for development of pests especially soil borne diseases. Irrigation water can be a source of water-borne pathogens, such as the bacterial wilt pathogen *Ralstonia solanacearum*.

Proper weed management including the destruction of volunteer plants is another key component of IPM practices. Weeds, beside competing with the crop for nutrients, also harbour many pests as do volunteer plants emerging from previous cultivations. For example, eliminating weeds in field borders is one of the cultural methods which may help to reduce the population and damage caused by cabbage aphids.

The use of mulch plays an important role in the prevention of pest and disease infestation, apart from important contributions to conservation of soil moisture and improvement of soil health and fertility and control of weed growth. Arthropod access to the soil surface around the crop plants is restricted by the mulch material applied. This can interfere significantly on the damage and reproduction of ground seeking pests, such as moths and root flies. Aphids, thrips and whiteflies can be significantly obstructed by coloured reflective plastic mulch, repelling these foliage seeking insects from the crop (Summers and Stapleton 2002). Mulch can also prevent splashing of rain hitting the ground, which stops the dissemination of fungal spores from the soil, important, for example, for early blight disease management, and it provides an attractive environment for ground living natural enemies.

Netting technology is used to reduce insect pest pressure and the need for insecticides. It is an efficient technology that can be used by smallholder vegetable growers. Insect nets applied on tomatoes, cabbages, beans and leafy vegetables protect them from flies and moths, and if maintained adequately also from whiteflies, aphids and thrips reducing their outbreaks as compared to open cultivation. It is widely used in nurseries to protect crops from viruses. Insect nets are safe and cost effective for a period of 3 to 5 years if well maintained, and they may be re-used and recycled. Insect nets applied on cabbages in Benin yielded 3-fold more profit than current practice. Netting is most efficient when integrated with other IPM practices, for example with companion plants as insect attractants or repellents (Martin et al. 2013).

Trapping and killing to reduce pest populations is a key IPM cultural control practice. Setting up yellow pan and sticky traps is effective for moths, aphids, whiteflies, leafhoppers, thrips, leaf miners, among others. Light traps with destruction of trapped insects are popular control practices and monitoring of nocturnal moths. Use of pheromones for mating disruption and kill zone creation, and especially the use of pheromone traps for mass trapping is becoming widely used where available.

Removal and destruction of egg masses, larvae, pupae and adults of insect pests, and also diseased parts of plants wherever possible is highly effective in small plots. Manually crushing larvae of *Tuta absoluta* and other leaf miners and handpicking of moth larvae, slugs and grubs is effective for smallholders and can dramatically minimize the invasion of these pests.

2.3 Monitoring, action thresholds

The presence of a few insect pests and some small amount of damage usually can be tolerated. The number of pests and level of damage beyond which treatment should be taken is known as the action threshold, a key component of IPM to reduce the negative impacts of excessive application of pesticide and save pesticide costs by only applying pesticides when necessary. Few thresholds have been established for pest management in developing countries, in part because of the lack of research in comparison with the large number of crops, pests, and different growing situations. Specific thresholds or control action guidelines may be difficult to determine, but thresholds can be developed over the long term by growers who regularly monitor crops and keep and evaluate good records. Using action thresholds instead of calendar based spraying, or when pest populations are already high and difficult to control, improve crop quality as fewer applications may improve plant growth by reducing phytotoxicity and the elimination of beneficial soil microorganisms. Less frequent applications help maintain pesticide efficacy by reducing the development of pesticide resistance.

Intervention, such as with pesticides, is reasonable when the expected cost of crop quality or yield damage exceeds the cost of the intervention, e.g. cost of pesticides and the application cost. The number of pests or damage that can be tolerated is determined by many factors, including the type of pest and damage, crop variety, growth stage, time until harvest or sale, and market conditions. Tolerance to pests can be higher if some plant parts are not marketed, such as older leaves on fruit, root or tuber crops. Thresholds can often be higher if effective or fast-acting methods are available for controlling the pest. On the contrary, if available intervention options are slow-acting or only partially effective, thresholds may be relatively low for that pest. Nursery plants and young plants should virtually have no pests. Close to harvest it may not be necessary to take action if pest levels are low and there is no time for the pest to reach a significant level before the crop is harvested. However, be aware action thresholds for crops with harvest that is stored over time are usually very low as even a minor infestation can develop further during storage.

Action thresholds can be established by systematically monitoring plants, keeping good records, and judging the acceptability of the finished crop in comparison with pest monitoring and control records.

It is important to experiment over time to adjust thresholds appropriate for the local situation. It is best to start with low thresholds and be flexible in adjusting the thresholds. Different thresholds can potentially be tested on different parts of the field or farm. Thresholds need to be quantitative or numerical to be useful. For example, thresholds could be based on the average number of pests per trap per week, the percent of plants or leaves found to be damaged or infested. Low threshold pests normally feed directly on the fruit and cause damage even at very low population densities. High action threshold pests at the other extreme of the continuum are normally those that feed on the foliage but not the fruit and cause no damage at all at low population levels. Action thresholds may also vary according to the insecticide used.

Weather conditions can also be used as action thresholds when weather factors are easy to measure and a tipping point conducive to disease development. For example, intervention action in the form of a protective fungicide spray is needed for tomato late blight disease when 1 day with more than 2 mm of rain is forecasted. If late blight infection risk is low: spray a preventive low risk fungicide every 7 to 10 days. If the infection risk is medium: spray a preventive fungicide every 7 days with an efficient contact fungicide. If the infection risk is high or symptoms are seen: spray fungicide every 5 days alternating efficient curative fungicides until the risk of infection has again been reduced. Action thresholds for fungal and oomycete diseases are very dependent on the crop variety being grown and its level of varietal resistance to each of these diseases.

Pest monitoring and simple action thresholds save unnecessary sprays compared to calendar applications and help farmers decide when to start with the first application with insecticides.

2.4 Biological control

Control of pests through biological means is an important component of IPM. Biological control is the use of living organisms, or products derived from living organisms, to control pests. The use of, for example, parasitoids, predators and pathogens to maintain insect pest populations below those causing economic loss are important biological control practices.

Biocontrol can either be done by introducing a new biocontrol organism or by increasing effectiveness of the natural pest enemies already present in the field. The latter is also called conservation biological control and uses habitat management to enhance the survival and impact of natural enemies for pest control. For this it is important to keep flowering plants for nectar and pollen, as sources of food for adults of natural pest enemies, such as predatory lacewings and parasitic wasps. Its advantages are that it relies on native or established natural enemy populations and do not require investment in off-farm material in the way that importation biocontrol does.

Botanical pesticides are also considered as biological control. They can be home-made from pesticidal plants such as neem or pyrethrum, which make them cheap and convenient for resource-poor farmers. Although not as effective as synthetic chemical pesticides, they can maintain insect pest levels below acceptable damage levels when applied frequently. Botanicals also have the advantage of a short or no preharvest interval (Amoabeng et al. 2020; Dougoud et al. 2019).

2.5 Chemical pesticide control

Tropical vegetable producers typically have easy access to old generic pesticide products. Overuse and unintended use of chemical pesticides is common by many smallholders. Wasteful use of pesticides is also common as farmers do not have access to information about proper use, and because cheap generic and broad-spectrum pesticides is often the only pest management option farmers have easy access to. This has led to innumerable cases of chemicals becoming worthless because of resistance development in pest populations, and secondary pest insurgences following the destruction of natural enemy populations. As a consequence, pesticide control by smallholder vegetable farmers under tropical conditions can typically be greatly improved through training in the safe and responsible use of pesticides, a key component of IPM and the most impactful in most tropical smallholder settings.

The main aspects of responsible pesticide use are listed in the following section with a focus on and prioritizing the economic, ecological and practical benefits for smallholders. The overarching principle being an integrated use that focuses on prevention and relies on cultural and biological control methods as first options when possible.

Firstly, as the level of risk from pesticide use and exposure is directly related to the volumes used, highly toxic chemistries and products used in high volumes are especially problematic. A fact overlooked by the majority of smallholder farmers and agrochemical dealers. Secondly, pesticide resistance management is, likewise, often not practiced by smallholders.

The negative impacts of pesticide use by smallholder farmers in the tropics can, therefore, be improved by training farmers, pesticide applicators and agrochemical dealers in appropriate pesticide selection and use, and should be a priority in the training of smallholder vegetable farmers under tropical conditions.

Pesticide selection training for tropical smallholders should focus on hazard categories and environmental impact indicators, informing farmers that risk is directly related with exposure, in other words, with pesticide volumes used and their hazard category. Risk to farmers can be reduced dramatically by selecting low hazard category pesticides and by reducing pesticide volumes used per application or over the entire cropping period without losing efficacy in control. Advising farmers to always use the recommended label dosages and not mixing commercial products with the same active ingredients are related pesticide management topics.

Pesticide resistance management is another training priority for smallholder vegetable growers in the tropics. Prevention of the emergence of pest populations resistant to pesticides, also called pesticide resistance management is crucial to responsible pesticide use. It is based on knowledge of pesticide active ingredients, their mode of action and alternating the application or mode of action groups and applying products containing different modes of action. In addition to alternation of pesticide mode of action groups, farmers should be trained in the overall use of IPM principles, including the use of cultural and biological control methods as first options when possible to avoid development of pesticide resistance.

Change in behavioural patterns among farmers, agrochemical sales personnel and pesticide applicators can be fostered by appropriate awareness raising and messaging. Smallholder vegetable farmers in the tropics have suffered by inappropriate promotion of dangerous chemicals by an agrochemical industry that intrinsic to its core business is interested in continuous increased use of its produce. Advisors in agrochemical stores are commonly paid commission on sales and therefore "push" for increased use. It is universal practice of the industry to present toxic pesticides with positive loaded words like "Plant Protection Products" to persuade society, politicians and farmers not to be afraid of the use of toxic chemicals. In many cultures, farmers have been led to view pesticides as medicines through exploitation of traditional cultural values to market pesticides (Mengistie et al. 2017). The result being that pesticides are not considered poisons, but products that cure pest problems. The industry typically describes pesticides as "Agents, used to manage pest which have been thoroughly tested for safety and usefulness before they are released for agricultural use". In contrast to this industry perception, many countries are banning the use of pesticide active ingredients previously legally registered and promoted by the agrochemical industry due to accumulating information about the hidden cost of chemical use and the long term negative effects on society.

The contradiction between the agrochemical sector's priorities, the short term economic benefit to the farmer, and on the other hand, societies benefit of avoiding intoxications, conserving natural resources and producing food without pesticide residues should be considered when training tropical smallholder farmers in crop protection.

In this context, IPM adoption is best promoted by clearly informing and if possible showing farmers the economic, ecological and practical benefits of IPM practices to them and their local community, and on the other hand, informing them about the risks associated with chemical pesticide use, especially related to unintended and worthless overuse.

Messages and concepts related to chemical pesticide control to be include in training events of smallholders:

- Pesticides are poison and should always be handled with extreme care.
- Insecticides are generally the most acutely toxic class of pesticides, but fungicides and herbicides can also pose risks to non-target organisms including human health, and do so when used in high volumes.
- The aim of delivering "clean" vegetables as opposed to with pesticide residues.
- Hazard categories, risk by exposure and preference for low risk pesticides.
- Pesticide selection criteria: i) selective for the pest type, ii) low health risk, iii) efficacy, iv) mode of action group, v) cost.
- How to transport and store pesticides.
- Label information should be made understandable to farmers.
- Trade names, active ingredients, mode of action groups, purchase of small packages/volumes.
- How to measure and prepare spray mixture, right dosage and volume per area.
- Integration of reduced fungicide rates in resistant crop varieties.
- Use and maintenance of application equipment.
- Correct disposal of containers and left-over pesticides.
- Restricted entry and pre-harvest intervals.
- Integration of chemical control into an overall IPM strategy.

3. Current and potential IPM practices for smallholder vegetable farmers in the tropics that effectively contribute to chemical control

3.1 Prevention practices

- ➢ Crop residue management including sanitation of fields after harvest by removing or burning all plant debris that can harbour pests.

- ➢ Avoiding monoculture with production system that grows and markets several vegetable crops throughout the year.

- ➢ Inter-cropping (polyculture cropping) with nitrogen fixing leguminous crops.

- Bacterial wilt, fungal and virus resistant crop varieties exist for a number of vegetable crops.
- Crop rotation by crop families.
- Planting trap crops on the borders of fields to attract and trap pests.
- Maintain flowering plants around vegetable fields to provides refuge and food for natural enemies.

3.2 Cultural control

- Timely weeding.
- Mulching for control of arthropod pests and pathogens, and to provide an attractive environment for ground living natural enemies.
- Netting technology applied to tomato, cabbage and leafy vegetables to protect them from flies, moths, and the virus vectors whiteflies and aphids, especially in nurseries.
- Stakes and trellising to reduce crop foliage ground contact and disease development.

3.3 Monitoring, action thresholds

- Weekly scouting (monitoring). Followed by, for example, application of botanical neem pesticide based on a threshold number of pests.
- Yellow sticky traps for monitoring insect pests.
- Pheromone monitoring and mass trapping of adult moths (*Helicoverpa*, *Spodoptera* and *Tuta*).

3.4 Biological control

- Biological seed treatments with *Trichoderma* fungi, *Pseudomonas* and *Bacillus* bacteria based products to protect seedlings from soil borne pathogens.
- Introduction biological control using the predatory mirid *Macrolophus pygmaeus* (MIRICAL, Koppert) for control of *Tuta absoluta*.
- Biofungicides based on *Trichoderma harzianum* fungus
- Bioinsecticides based on *Beauveria bassiana* fungus
- Bioinsecticides based on nucleopolyhedrovirus (NPV)
- Botanical insecticides made from neem, chili pepper, garlic, *Annona squamosa*, *Dysphania ambrosioides* and *Tephrosia vogelii*.
- Conservation biological control by planting, for example, *Ageratum conyzoides*, *Tridax procumbens* (*Asteraceae*), *Crotalaria juncea* (*Fabaceae*), *Cymbopogon citratus* (*Poaceae*) or

Lantana camara (*Verbenaceae*) in crop borders to provide floral resources and shelter for natural enemies.

4. Socio-economics of smallholders: Concepts to be considered for recommendation of IPM

Tropical vegetable farming can be undertaken by farmers representing a resource continuum from very poor to very resourceful. Smallholders are typically resource-poor and will therefore prefer approaches and technologies that require few assets, have a lower risk premium, and are less cash dependent. This is indeed also the case for smallholders that have moved away from subsistence production. For tropical conditions, it makes sense to make recommendations for smallholders as opposed to recommendations for larger commercial growers.

IPM is knowledge intensive, which can make it complex to comprehend and implement. For less resourceful smallholders, not used to complex decision making, it is therefore key to introduce new IPM strategies in a simple and stepwise manner.

Introducing technologies that require less labour is also likely to lead to higher adoption. Although time and manhours is one resource smallholders may have with the aid of family members and neighbours, they are still likely to be in shortages of labour during the peak moments in the cropping season.

Uncertainties, in addition to the poor economy of many smallholder farmers, are another important factor that smallholders face, such as, if enough or too much rains will come. Smallholders are therefore reluctant to invest their restricted cash in technologies that could potentially improve the crop, because, on the other hand, there may be no crop to harvest at all. Many costly technologies may also only payoff it there is a co-investment in companion technologies. For example, investment in crop protection only makes sense if there is also investment in fertilizer, and investment in net technology if there is investment in fertilizer and irrigation and so on.

Smallholders are more likely to adopt IPM technologies that can be based on locally available assets. This is one of the strengths of homemade botanical pesticides (typically 10-fold cheaper than chemical pesticides). A weakness is the amount of time needed to prepare them and frequently apply. The reason intercropping crop species is probably the most common integrated crop management practice used is its no-requirement of cash or investment in labour.

IPM practices are more feasible for smallholders if there is a link with culturally accepted and traditional farming practices. Conservation biological control is similar to traditional intercropping practices, as is cultivation of companion plants, mulch and green manure crops. These technologies can be considered relatively cheap and similar to traditional practices. This type of practice can therefore more easily be adopted by smallholders.

The wide acceptance of chemical pesticides also indicate that at least some farmers have a preference for new and impressive technologies brought in from outside the community. A farmer adoption factor that should also be considered for the introduction of new IPM practices.

A farmer's decision of whether and how much of an input like pesticide or fertilizer to use depends on the price of that input and the expected return on investment. For the training in IPM technologies it is key to consider what material is locally available to farmers. Trade costs, the total costs involved in getting a product from a producer in one location to a consumer in another is much higher in developing countries and in remote areas than elsewhere in the world (Donaldson et al. 2017). Additionally, many smallholders deliver their produce to markets with very variable prices.

The economic profitability of an IPM innovation depend on the efficacy of the innovation and the value of the crop produce. The higher crop value the more profitable the IPM innovation may be. The more efficacious the more profitable. The lower the cost of the innovation the more profitable the innovation.

Growers' level of market connection can be a guideline for their interest in IPM investment, considering the market's quality requirements. A strong motivation factor being markets buying vegetables of high quality with no pesticides for export or local markets. Reduced chemical use is often a necessity to reach export markets like the EU. Nevertheless, smallholders are not likely to adopt IPM as a package but rather select components of the IPM package that are affordable and easy to apply and maintain in their particular situation. While they will make some profit on new well implemented IPM technologies, it is insufficient to finance the very high initial investment of many complete IPM packages. If the market value of harvested produce varies a lot then the risk of no return on investment is high. Uncertainties significantly make investments less attractive as the return on investment is uncertain. A common situation for many smallholders.

Smallholders in some cultures may not adopt innovations that are profitable or environmentally friendly if they are not convinced of a moral or social benefit leading to community acceptance, or if the innovation disturbs traditional power relationships in their community (Mzoughi 2011).

Year-round production in the tropics can involve out of season farming. For example, cropping during the dry season can result in higher profits because vegetables are more in demand in the out of season period compared to in season when supply is higher. Dry season farming is likely to be more costly (irrigation and other additional cost) but may result in a higher profit margin. Out of season farming is likely to involve a change in pest pressure and management.

As market price vary within planting dates across the season, planting date adjustment to avoid pests is unlikely to be adopted by large commercial growers, but may be valuable for smallholders.

The reality of regulations related to pesticide use for smallholder farmers under tropical conditions is very different from the enforcement in developed countries. Registration of pesticides is based on paperwork and less on real tests of efficacy and health risks. Quality control is often not implemented. There is no training or accreditation of agrochemical sales personnel. Labelling of products is also often not controlled. Pesticide use is left to an uncontrolled market of costumers unaware of the appropriate use. In view of this suboptimal situation, it should be considered that smallholders also often consider the economic impacts of pesticide use on crop yields and farm profitability alone.

5. Conclusion

The most common practice in pest management continues to be the use of broad-spectrum generic chemical pesticides. New and selective pesticides are often not affordable to smallholders or they are not aware that there are other types of pesticides. Vegetable growers and extension agents supporting the growers often have limited knowledge about the proper use of pesticides, especially the associated health hazards. While the returns from high insecticide input may appear high in the short term, in the longer term the disadvantages outweigh the benefits. There are now many well documented examples of how, when insecticides were used prophylactically over a number of years, insecticide resistance developed, secondary pest insurgence occurred, natural enemy populations were destroyed and eventually insecticide use no longer constituted a viable control method. Compacting this situation is the fact that many smallholders and agrochemical dealers are not aware that the risk from pesticide use and exposure is directly related to the volumes used. Products used in high volumes are especially problematic, as are highly toxic chemistries (some insecticides).

Training smallholder vegetable growers in the health hazards that can be caused by unintentional use of pesticides as well as the availability of IPM alternatives and tools in their locality are key priorities for crop protection improvement for smallholder vegetable growers under tropical conditions. Acknowledging that smallholders prefer approaches and technologies that are less resource-intensive. Awareness about the negative impacts of indiscriminate pesticide use is important for significant real change in tropical crop protection traditions. Messages such as "Grow a clean crop" should be widely disseminated.

Farmer capacity building to increase farmers understanding of IPM principles is key to successful IPM training. IPM requires good knowledge and understanding of individual and local production systems; identifying pest species, knowing their biology and symptoms of infestation is essential for making educated decisions on their integrated management. IPM is knowledge intensive, which can make it complex to implement. It is therefore key to introduce new IPM strategies in a locally adapted, simple and stepwise manner. The farmer is the primary decision-maker in the implementation of crop protection options and to equip the farmer with an understanding of the critical relationship between horticultural output and field ecology is the most effective process for implementing IPM. Location-specific training, focusing on the most destructive pests affecting the local production system has much higher impact than focusing on general training programmes, as these key pests are likely to receive all attention from farmers and involve the vast majority of their management investment.
This report concludes that IPM options are more cost-effective than the conventional overuse of chemical pesticides. IPM results in larger profits for the farmer, along with better quality vegetables for local and international markets if farmers receive and implement the right learning objectives.

6. Recommendations

Recommendations on how to maximize crop protection strategies are presented below. Training in IPM should always include an introduction to IPM, including the negative and hidden effects associated with synthetic chemical pesticide control, and IPM's main components to give a holistic perspective of the integrated approach that is the core of any IPM strategy. Farmers' skills in identifying pests and their understanding of IPM principles is the key to successful IPM implementation. IPM strategies should always be adapted to the local conditions of weather, pest populations, market prices of produce and inputs. To facilitate the implementation of IPM and the definition of learning objectives for training events, the recommended IPM practices listed below begin with the highest priority followed by the next highest below and in subsequent order, and considering the least complex practices by each of the main IPM components: prevention, cultural control, monitoring, biological control and chemical control.

Prevention practices

- Resistant crop varieties
- Crop rotation by crop families
- Inter-cropping and polyculture with selected companion crops

Cultural control

- Stakes and trellising for tomato and similar crops
- Mulch to reduce pest pressure
- Insect net-cover

Monitoring, action thresholds

- Trap based monitoring and decision making, rather than the use of calendar spraying
- Yellow sticky traps for monitoring and mass trapping
- Pheromone trapping for monitoring and mass trapping

Biological control

- Biocontrol pesticides (*Trichoderma*, *Pseudomonas*, *Bacillus*, neem)
- Homemade botanical insecticides made from neem, chili pepper, garlic, Annona squamosa or *Tephrosia vogelii* cultivations grown locally.
- Conservation biological control by planting, for example*, Ageratum conyzoides, Tridax procumbens, Crotalaria juncea, Cymbopogon citratus or Lantana camara* in crop borders to provide floral resources and shelter for natural enemies.

Chemical pesticide control

- Use label recommended rates only (Do not mix commercial products)
- Appropriate information about access to new efficient pesticides to avoid use of old broad-spectrum high risk pesticides
- Alternate pesticides from different mode of action groups in a pesticides resistance management strategy
- Use low-risk pesticides (by pesticide hazard categories)
- Use selective pesticides, such as:
    - Pirimicarb – targets aphids
    - Indoxacarb – target moth larvae, mirids
    - Pymetrozine – targets aphids, whitefly, planthoppers, mealybugs, beetles
    - Chlorantraniliprole – targets moth larvae
    - Cyromazine – targets leafminer fly
- Integrate highly selective low-risk pesticides with biocontrol products:
    - Mineral oils for aphid and whitefly control
    - *Bacillus thuringiensis* moths and moth larvae
    - Neem based products for whiteflies, aphids, leafminers, moth larvae
    - NPV for *Helicoverpa*
- Integrate fungicide use with varietal resistance (reduced rate in resistant varieties)

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