Achieving rational pesticide use in outdoor tomato production through farmer training and implementation of a technical guideline

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Smallholder farmers were trained by frontline extensionists and local experts on how to apply Integrated Pest Management (IPM) in outdoor tomatoes, Solanum lycopersicum, during farmer field schools in Northern Tanzania between 2005 and 2008. Farmers were also organised into newly-established vegetable producer clubs within which they developed a technical guideline defining the minimum requirements for integrated tomato production. Unaligned, clustered sample surveys conducted among farmers trained in IPM and conventional farmers between 2009 and 2010 revealed that IPM farmers adopted and/or more frequently used non-hazardous preventive measures for pest (arthropod, disease and weed) control than non-IPM farmers. However, pest incidence was so severe during these years that nearly every IPM and non-IPM farmer had to use synthetic pesticides as a direct control measure. Overall, IPM farmers sprayed synthetic pesticides in smaller quantities and less frequently than non-IPM farmers, but they applied natural source pesticides more frequently and in larger amounts. IPM farmers used 85% less often the more hazardous pesticides (WHO toxicity Class I and II) than non-IPM farmers, as well as 42% more often the less hazardous pesticides [Class III and U (=IV)], and 84% more often ‘green’ products (for example, biological, safe botanicals). In conclusion, the training of farmers in IPM, together with the implementation of a technical guideline and the establishment of producer clubs, is highly recommended for reducing the use of hazardous pesticides and improving the production of vegetables that are safer for producers, consumers and the environment.

Key words: Integrated pest management (IPM), farmer training, technical guideline, project monitoring and evaluation, vegetable producer clubs, Solanum lycopersicum, pesticide reduction, Tanzania.

INTRODUCTION

The tomato (Solanum lycopersicum L.) is of great importance to smallholder farmers in the Kilimanjaro and Arusha regions of the northern zone of Tanzania in terms of local consumption and income generation (Barry et al., 2009; Djurfeldt et al., 2010). Smallholder farmers usually grow tomatoes outdoors all year round in Northern Tanzania if there is sufficient rainfall or the availability of irrigation. Main production periods are from March to May...
and during November and December when regular rainfall is expected. A tomato cropping cycle lasts 11 to 13 weeks. A dry period usually occurs from July to September and can occasionally be so serious that vegetable production becomes impossible (Page et al., 2010). Typically, smallholder farmers own 0.2 to 10 acres of land of which 0.05 to 3 acres are under tomato production (Table 1). In terms of education, most farmers have completed at least primary school level education (Table 1) and some family members can read and write. 65 to 84% of farmers are males. Farmers usually sell their produce in local rural markets often on roadsides, or to urban markets through middlemen (Fleuret, 1984; Barry et al., 2009; Black et al., 2001; Djurfeldt et al., 2010). Successful tomato growing and marketing can generate a significant income for farmers (James et al., 2010).

**Tomato varieties and their pests**

A large number of tomato varieties are grown in Northern Tanzania, including Onyx, Tengeru, Marglobe, Cal J and Tanya, of which most are resistant to various forms of blight, virus or wilt (Dobson et al., 2002; TOSCI, 2009). Several of these varieties, such as Tengeru 97, are tolerant to late blight, fusarium wilt, tomato mosaic virus, tomato yellow leaf curl virus (TYLCV) and/or root-knot nematodes. Others, such as Rio Grande, can tolerate early and late blight, as well as fusarium wilt. The Kentom variety is tolerant to bacterial wilt, root-knot nematodes and tomato mosaic virus. The Roma VFN variety is tolerant to *fusarium* and *verticillium* wilt, root-knot nematodes and red spider mites, and the Roma VF variety is tolerant to fusarium and verticillium wilt (Dobson et al., 2002; TOSCI, 2009).

Tomato production in Northern Tanzania suffers from arthropod pests such as *Bemisia tabasi* (white flies), *Agrotis* spp. (cutworms), *Helicoverpa armigera* (bollworm/tomato fruit worm), *Tetranychus* spp. (spider mites), *Bactrocera cucurbitae, Bactrocera zonata* and other *Bactrocera* species (mango fruit flies) and several flower and leaf thrips (Bohlen, 1978; Swai et al., 2000; Kaoneka et al., 2004; ICIPE, 2005, 2006; Ekesi et al., 2010). Major diseases include *Phytophthora, Pythium, Alternaria, Rhizoctonia,* and *Fusarium* spp. (all water moulds or damping-off fungal diseases). These include *Alternaria solani* (early blight fungus), *Phytophthora infestans* (late blight water mould) (Mlungu and Godwin, 1996), *Fusarium oxysporum f.s. lycopersici* (fusarium wilt or basal rot fungus), *Ralstonia solanacearum* (bacterial wilt) (Black et al., 1999; Fleuret, 1984), *Xanthomonas campestris pv. vesicatoria* (bacterial spot) (Black et al., 2001), *Sclerotinia sclerotiorum* (soft rot fungus), *Leveillulataricia* (powdery mildew fungus), tomato mosaic virus (Chiang et al., 1997) and TYLCV (Nono-Womdim et al., 1996).

*Meloidogyne* nematode species can cause serious damage to tomato roots (Ijani and Mmbaga, 1988; Swai et al., 1996). A number of weeds can be frequently found in tomato fields, but can usually be managed through mechanical control.

**Training in integrated pest management (IPM)**

A certain lack of farmer knowledge in controlling the numerous tomato pests, together with inadequate access to information on safe pesticides (WHO, 2009; TPRI, 2010) and their use had led to inappropriate use of these chemicals (Ngovi, 2002). This was characterised by the application of large quantities of pesticides, the use of hazardous products, incorrect formulations/preparations and dosages, mixing of various products with different active ingredients and toxicity classes, and a lack of awareness of pre-harvest intervals (Kaoneka et al., 2000; Ngovi et al., 2007). This in turn had resulted in the sale of tomatoes that were contaminated with pesticide residues (Kaoneka et al., 2000; Ngovi, 2002; Ngovi et al., 2007). Therefore, farmers were trained in IPM during four to six season-long outdoor sessions between 2005 and 2008 using discovery-learning approaches in farmer field schools (FAO, 2000; Mbwaga and Hayden, 2003; Kilimo 2005).

In order to improve farmer knowledge about the safe use of pesticides, 18 village extension officers of local governments under the Ministry of Agriculture, Food Security and Cooperatives attended two training courses in 2005 and 2006 to become trainers for farmer participatory IPM training. As a result, extension officers learned about integrated production of tomatoes and non-formal education methods (Pretty et al., 1995; Mbwaga and Hayden, 2003; Kilimo, 2005), and also developed an IPM training curriculum for farmer field schools including information on alternatives to synthetic pesticides. With the support of these trained extension officers and IPM experts of the National Horticultural Training Institute (HORTI) at Tengeru, Tanzania, eight tomato farmer field schools were established between 2005 and 2008 and farmers were trained over the course of four to six tomato cropping cycles. Each farmer field school consisted of 10 to 25 farmers and therefore a total of 150 to 170 farmers were trained in integrated outdoor tomato production. During the training period, scientific and indigenous knowledge was exchanged between farmers, frontline extension officers, and local and external IPM experts.

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Sustainable pest management solutions (Boller et al., 2004; Kaoneka et al. 2004; Malavolta et al., 2005; Pesticide Action Network, 2005) were selected, validated and adapted to local conditions and beneficiaries’ needs. Alternatives to broad-spectrum pesticides and other hazardous products were also identified.

Implementation of a technical guideline

Between 2008 and 2009, a technical guideline for integrated tomato production in northern Tanzania was developed (Massawe et al., 2010) defining the minimum agricultural requirements for a more sustainable production system (Kilimo, 2005; Malavolta et al., 2005; Ernest and Njogu, 2007; WHO, 2009; TPRI, 2010). This was achieved through the joint efforts of IPM experts of HORTI Tengeru, frontline extension officers tomato farmers of vegetable producer clubs, agro-input dealers, CABI Africa, and CABI Europe- Switzerland. The technical guideline was compiled using experiences and lessons learned from 2005 to 2008, as well as international standards, such as those defined by the International Organisation of Biological Control (Boller et al., 2004; Malavolta et al., 2005), and local standards (TPRI, 2010; TOSCI, 2009). Overall, it defines and explains the minimum requirements for the implementation of integrated production (Boller et al., 2004) of fresh outdoor tomatoes (WHO, 2009; Ernest and Njogu, 2007; TPRI, 2010) based on local and regional knowledge obtained during the 3 years of farmer IPM training from 2005 to 2008, as well as international standards as defined by the Commission of the International Organization of Biological Control (IOBC) (Boller et al., 2004; Malavolta et al., 2005) and other relevant local standards. The requirements relate to biological diversity and landscape, site selection and management, cultivars, seeds, seedling production and transplanting, nutrition, irrigation, IPM, harvest, post-harvest management and tomato storage. Two of the major IPM requirements include the implementation of preventive (= indirect) measures, and the monitoring and consideration of pests and weather conditions prior to intervention with direct pest management measures. To support these principles, a list of economically important pests (arthropods, diseases and weeds) that require regular control measures in northern Tanzania was developed, as well as lists of nutrient deficiency symptoms and the most important site-specific natural enemies. A Green and Yellow Lists were also developed to guide the choice of relevant preventive and direct plant protection measures. The Green List consists of preventive and selective direct control measures, which have no negative impact on humans, non-target organisms and the environment (for example, biologicals, safe botanicals, minerals, soaps, bio-technicals). It also defines action thresholds to facilitate the decision for or against direct control measures. The Yellow List defines direct plant protection products that may be used, including their restrictions if applicable, by the producer if pest monitoring signifies a need for intervention. Direct plant protection measures selected for the Yellow List were the least hazardous to humans, livestock and the environment (WHO toxicity Classes III and IV (=U)). Hazardous pesticides of WHO toxicity Classes I and II pesticides were considered as ‘Red’ products with the intention of them being phased out. All products recommended on the Yellow List had to be officially registered, and were only to be used in compliance with their maximum permitted total dose and pre-harvest interval. The use of chemical herbicides was not permitted within the integrated production system.

The IPM practices, defined in the technical guideline, were implemented by farmers in vegetable producer clubs for integrated tomato production from 2009 onwards in the Hai, Moshi, and Arusha districts of Northern Tanzania by which time the farmers were expected to have obtained sufficient knowledge and skills to produce tomatoes using IPM. The guideline was enforced via a producer club-endorsed self-evaluation checklist for successful IPM implementation.

Establishment of vegetable producer clubs

Farmers transformed seven of the eight above-mentioned farmer field school groups into officially registered vegetable producer clubs for integrated tomato production in 2009 and 2010 with the primary aim of developing and implementing a marketing system for their tomatoes based on the work of Djurfeldt et al. (2010) and Mithoefer and Waibel (2011) (Table 1). The concept of establishing producer clubs was adopted for several reasons, including to increase the power of farmers, to ensure the production of tomatoes according to an agreed technical guideline (see above), and to help farmers penetrate existing tomato markets with their improved product (Agwanda et al., 2010; Mithoefer and Waibel, 2011). The accessing of such markets would in turn help to ensure a secure and safer income for the farmers (Table 1). It was hoped that farmers would profit due to reduced production costs resulting from decreased pesticide use. The vegetable producer clubs were located in Kimbima, Kiwanyanu, Faru, Nduruma, Nguvukazi, Songambele and Upeneema of the northern zone of Tanzania (Table 1). Each one consisted of 10 to 25 farmers, that is, 130 to 150 IPM farmers in total.

Does IPM training affect farmer behaviour?

The extent and quality of IPM implementation after training was still unknown as it is often difficult to tell to what extent the farmer training activities exhibit real
Table 1. Characteristics of tomato-growing farmers in the northern zone of Tanzania between 2009 and 2010.

<table>
<thead>
<tr>
<th>Category</th>
<th>Age of farmers (years) (Mean ± SD)</th>
<th>Gender % males (Mean ± SD)</th>
<th>Highest formal education (%)</th>
<th>Land owned (acres*) (Mean ± SD)</th>
<th>Under tomato (acres*) (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPM farmers (n = 204)</td>
<td>47 ± 10</td>
<td>65 ± 48</td>
<td>None or non-formal 27%</td>
<td>1.9 ± 1.7</td>
<td>0.6 ± 0.5</td>
</tr>
<tr>
<td>Non-IPM farmers (n = 70)</td>
<td>41 ± 10</td>
<td>84 ± 37</td>
<td>Primary school 63%</td>
<td>1.8 ± 1.7</td>
<td>0.6 ± 0.5</td>
</tr>
<tr>
<td>All (n = 274)</td>
<td>45 ± 10</td>
<td>70 ± 46</td>
<td>Secondary school 63%</td>
<td>2 ± 1</td>
<td>1.8 ± 1.7</td>
</tr>
</tbody>
</table>

*, 1 acre = 0.4 ha

Differences often claimed by farmer field school practitioners (Federer et al., 2004; Van der Burg, 2004; Tripp et al., 2005; Erbaugh et al., 2010). Moreover, it was uncertain whether farmer education, the implementation of a technical guideline and/or the establishment of vegetable producer clubs with production rules had indeed led to more rational use of pesticides. In other words, it was not possible to tell whether the international development projects and donor investments behind these activities had really made a change (Tripp et al., 2005; Erbaugh et al., 2010). International development projects have recently come under the microscope and many question the efficacy of farmer training programmes (Erbaugh et al., 2010; Gilbert, 2013).

In order to address this question unaligned, clustered sample surveys were conducted among IPM-trained tomato-growing smallholder farmers organized in seven vegetable producer clubs in or around six villages, as well as with non-IPM smallholder farmers in or around seven villages (Table 2). Villages were in the Moshi and Hai district of the Kilimanjaro region, and in the Arusha district of the Arusha region, all in the northern agri-ecological zone of Tanzania (Table 2). Surveys were implemented between 2009 and 2010 through questionnaires and interviews carried out by local extension officers as next shown.

Materials and Methods

Survey area

The surveys were conducted with IPM-trained tomato-growing smallholder farmers organized in seven vegetable producer clubs in or around six villages, as well as with non-IPM smallholder farmers in or around seven villages (Table 2). Villages were in the Moshi and Hai district of the Kilimanjaro region, and in the Arusha district of the Arusha region, all in the northern agri-ecological zone of Tanzania (Table 2). Surveys were implemented between 2009 and 2010 through questionnaires and interviews carried out by local extension officers as next shown.

Survey on effects of farmer training, technical guideline implementation and producer club establishment on rational use of pesticides

To investigate the extent and quality of implementation of the IPM practices by the trained farmers and whether farmer training, technical guideline implementation (Massawe et al., 2010), and producer club establishment had indeed led to a more rational use of pesticides (Van der Burg, 2004), surveys were conducted among two target populations: (a) farmers trained in IPM and organized in seven vegetable producer clubs as described above, and (b) non-IPM farmers in the same project districts of Moshi and Hai in the Kilimanjaro region, and Arusha in the Arusha region of northern Tanzania.

The survey followed an unaligned, clustered sample design (Bharati et al., 2004; Haarstad et al., 2009) as farmers were organized into unaligned producer clubs (clusters) in the three target districts. The sampling unit was the farmer, which in most cases equaled a farm household. Three surveys were implemented over time to allow the analysis of possible temporal changes. The study populations were as follows: i) 51 IPM farmers fully trained in IPM procedures but not organized into producer clubs and without a technical guideline, (surveyed in January/February 2009); ii) 83 IPM farmers just starting to produce according to a technical guideline (surveyed in November/December 2009); and iii), 70 IPM as well as 70 non-IPM farmers were surveyed in July/August 2010 to allow the analysis of change between IPM and non-IPM farmers (Table 2). Farmers were arbitrarily chosen. Occasionally though, the same or different farmers were interviewed over time.

Surveys were implemented through structured interviews with single or pairs of farmers and based on questionnaires. They were carried out by local extensions officers, facilitated by IPM experts of the HORTI Tengeru centre in Arusha and survey experts of CABI Africa from Nairobi. Surveys followed the methods devised by Bharati et al. (2004), Haarstad et al. (2009) and Tongco (2007) and reviewed by Gilbert (2013). In total, 274 interviews...
Table 2. Location and number of surveyed IPM and non-IPM farmers in the northern zone of Tanzania.

<table>
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<tbody>
<tr>
<td>Arumeru</td>
<td>Nduruma</td>
<td>9</td>
<td>19</td>
<td>Nduruma</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>Arumeru</td>
<td>Kivululu</td>
<td>10</td>
<td>13</td>
<td>Songambele</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Arumeru</td>
<td>Uwiro</td>
<td>10</td>
<td>5</td>
<td>Nguvukeni (Ngare Nanyuki)</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Moshi</td>
<td>Kilema Pofo</td>
<td>10</td>
<td>12</td>
<td>Upeneema</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Moshi</td>
<td>Kilema Pofo</td>
<td>10</td>
<td>14</td>
<td>Faru</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Hii</td>
<td>Mungushi</td>
<td>2</td>
<td>10</td>
<td>Kimbimba</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Hii</td>
<td>Mudio</td>
<td>0</td>
<td>10</td>
<td>Kivanyamu</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>7</td>
<td>51</td>
<td>83</td>
<td>7</td>
<td>70</td>
</tr>
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</table>

were conducted. Questions aimed to clarify whether the tomatoes produced according to IPM methods were likely to be safe for producers, consumers and the environment due to reduced use of hazardous pesticides. The questions were in most cases open questions, and largely indirect, that is, requesting costs of control measures, such as pesticides. But overall, they were designed to quantify the extent to which IPM or non-IPM measures were implemented and whether the use of hazardous pesticides was reduced as a result of IPM implementation. Questions focused on obtaining quantitative and semi-quantitative impact indicators for: (a) the adoption of non-hazardous preventive measures against pests, (b) the support of plant health using balanced fertilization, (c) the implementation of pest monitoring for improved decision making regarding the application of control measures, (d) the phase-out of hazardous direct pest control measures and the adoption of less- or non-hazardous methods, (e) the reduction in quantity and frequency of pesticide use, and finally, (f) the misuse of pesticides. The survey did not investigate qualitative learning processes, but quantifies learning outputs and impact as a result of learning successes.

Analyses of survey data

Data of survey variables were visually analysed for normal distribution using histograms and Q-Q plots (Kinnear and Gray, 2000). The influence of time since becoming an IPM farmer was analysed on the assessed survey variables using general linear models depending on distribution of data, lack of many extreme, for example, 0 or 1 proportional data, and independency of variables. As only two or three time periods were compared (January/February, 2009, November/December, 2009 and July/August 2010), parametric independent samples Welch T test was used to compare the means of variables in cases of normal distribution of data or sample sizes of more than 40, which was the most common scenario. In only a few cases, the non-parametric independent samples Mann-Whitney U test was used. The same comparison tests were applied when comparing IPM-trained farmers producing according to a technical guideline with IPM-trained farmers with no guideline to follow and non-IPM farmers. Only when comparing many different IPM practices or different classes of pesticides used, PostHoc multiple comparison tests were applied after having clarified the equality or inequality of variance using analysis (ANOVA). This was, the Tukey test in cases of equal variances, the Dunnett test in cases of equal variances but with extreme data points, or the Games Howell test in case of unequal variances.

RESULTS

Reported tomato varieties and their pests and diseases

Among the 274 interviewed farmers, a large number of tomato varieties are grown. The most preferred varieties are Onyx (31%), Tengeru 97 (19%), Marglobe (12.3%), Cal J (11.9%), and Tanya (6.5%). The most important arthropod pests were considered to be B. tabasi (21%), H. armigera (11%), red Tetranychus spp. (10), and Bactrocera spp. (8%). About 3% of farmers reported no major problems with arthropod pests. Phytophthora late blight was considered the most important disease according to 19% of the 274 farmers interviewed, L. taurica mildew fungus by 12% of the farmers, bacterial or fungal wilts by 9% and TYLCV by 4%. Approximately, 13% of the farmers claimed not to have major problems with diseases.

Adoption of non-hazardous preventive measures against pests

IPM farmers used non-hazardous preventive measures for arthropod, disease and weed control more frequently than non-IPM farmers (Figure 1) (GLM: df = 213;9, F = 1412, p < 0.001).

Mulching was used up to 3 times more extensively for weed control, moisture retention in the soil, and predator enhancement by IPM...
farmers than non-IPM farmers (July/August, 2010: 60 versus 20%, Figure 1). The use of mulching increased among IPM farmers from 45% in 2009 to 60% in 2010.

Mixed cropping of garlic or onions between tomatoes was frequently used by IPM farmers to repel pests, but less so by non-IPM farmers (Figure 1). IPM farmers used this method intensively in November/December, 2009 (94 ± 9 SD%), but to a less extent in July/August, 2010 (24 ± 7%). This is due to particularly high pest pressure in November and December when weather conditions are optimal, that is, relatively wet, compared to August. The same trends can be observed for the use of raised seed beds to avoid standing water and subsequent problems with soil borne diseases, which was used by 83 to 86% of the IPM farmers, and 74% of non-IPM farmers.

Disease tolerant varieties, such as Tengeru 97, Rio Grande, or Kentom were used more frequently by IPM farmers than non-IPM farmers (77 to 94% versus 56%, Figure 1).

The staking of tomato plants for improved aeration and prevention of disease transfers was used to a higher extent by IPM farmers (17 to 91%) than by non-IPM farmers (about 5%). The use of staking decreased among IPM farmers from 91% in November/December, 2009 to 17% in July/August, 2010. In the latter period, however, it is common practice to grow varieties that are traditionally not staked, for example, the common oval shaped tomato varieties, such as Tanya, Onyx, CAL-J or Rio Grande. In November/December, however, other varieties such as disease tolerant ones are grown; but they often require staking, such as the variety Tengeru 97.

Support of plant health using balanced fertilization

Most farmers applied fertilizers, regardless of whether they practiced IPM or not. In November and December 2009, however, IPM farmers applied less fertiliser than IPM or non-IPM farmers in other cropping seasons, which was likely to be due to prolonged drought (Figure 2).

A larger proportion of IPM farmers with technical guidelines used animal manure than IPM farmers without technical guidelines (Figure 2). In 2010, twice as many IPM farmers used animal manure than non-IPM farmers (86 ± 12% versus 42 ± 11%).

A larger proportion of IPM farmers produced and used compost for fertilization than non-IPM farmers (19 to 39%...
versus 6%). A larger proportion of IPM farmers used green manure, such as *Crotolaria* spp. (Sunhemp) or legumes, between tomato cycles to improve soil quality than non-IPM farmers (11 to 34% versus 3%).

**Use of monitoring of pests and diseases for decision making**

Nearly all farmers, regardless of whether they produced according to IPM standards or not, checked, at least occasionally, for the presence of arthropod or disease pests in their tomato fields (100 ± 0% IPM farmers with technical guideline and 98 ± 4% non-IPM farmers in July/August 2010, M.-Whitney U test’s p > 0.05). A larger proportion of IPM farmers regularly monitored (= scouted) infestation levels over time for better decision-making than non-IPM farmers (92 ± 8% and 79 ± 6% for IPM versus 44 ± 3% for non-IPM farmers, M.-Whitney U test’s p < 0.05). Slightly more IPM farmers conducted regular monitoring in November/December, 2009 (92 ± 8%) than in July/August 2010 (79 ± 6%), likely due to the higher pest pressure in November and December.

Nearly all IPM farmers (99 ± 2%) conducted Agro-Ecosystem Analyses (AESA) in their tomato fields, in contrast to only one fourth of the non-IPM farmers (23 ± 5%). Where AESA was applied, IPM farmers conducted it about twice as often as non-IPM farmers (2.1 ± 0.3 AESA/week versus 0.9 ± 0.3 per week over the approximately 12 week cropping season).

Nearly all IPM farmers kept records (mostly on the template record sheets provided to them), that is, significantly more than non-IPM farmers (97 ± 6% versus 58 ± 4%, M.-Whitney U test’s p < 0.05). The latter, however, had not been provided with template record sheets.

**Phase-out of hazardous pesticides and adoption of less hazardous, direct control measures**

IPM farmers used hazardous pesticides (WHO toxicity Classes I and II, here synonym ‘Red products’) 27 to 84% less frequently than non-IPM farmers (Figure 3); but in general farmers rarely used products from the most hazardous class I, regardless of whether they were an IPM or a non-IPM farmer.

By 2010, IPM farmers used 84% less often hazardous products than non-IPM farmers, 42% more often Yellow pesticides than non-IPM farmers, and 84% more Green products than non-IPM farmers. Moreover, from early 2009 to late 2010, the use of hazardous pesticides
among IPM farmers decreased by more than 60%. The use of hazardous products was almost phased out by 2010 (Figure 3).

When considering synthetic pesticides, IPM farmers mainly used products of WHO toxicity classes III and U (=IV) (52 to 70% more than non-IPM farmers). In contrast, non-IPM farmers mainly used the more hazardous class II products (26 to 73% more than IPM farmers).

Among IPM farmers, the use of hazardous synthetic pesticides of Class II decreased by approximately 21% with time. The use of class III products remained largely stable, but the use of class U (=IV) products increased by 29%. This might be due to the fact that Class II products are sometimes more effective at controlling arthropod and disease pests than Class III or U (=IV) products, and so more frequent sprays of the latter may be required.

The application of a number of hazardous pesticides was phased out over the duration of the study. For example, the Class 1b insecticide dichlorvos, and the Class II insecticides dimethoate, alpha-cypermethrin or other cypermethrins. The phase out of all remaining Class II insecticides was on-going and expected to be achieved by early 2011. These included various products based on deltamethrin, lambda-cyhalothrin, endosulfan, profenofos or chlorpyrifos.

The following eight Green or Yellow products were made locally-available during the project period: the Neem-based botanical insecticides (Nimbecidine; Neem oil extracts, Neem seed cakes, Neem seed powders), some mancozeb-based fungicides and liquid copper.

The following 12 Green or Yellow products were locally available prior the project, but most farmers were either unaware about their existence or unclear as to how to apply them. Their knowledge in this respect was improved during the project with regard to the following insecticides/acaricides: horticultural oil (for example, sunflower oil), liquid soap, and sprays made from garlic bulbs, onion, mentha, papaya leaf, ground marigold, and maize flour. Knowledge about various fungicides was also enhanced, for example, chlorothalonil + carbendazim-based products, hexaconezole-based products, lemongrass spray and baking soda – horticultural oil sprays (Figure 4).

### Reduction of pesticide use

Almost every farmer indicated that they use synthetic pesticides to control arthropods and diseases (96.1% of IPM farmers in January/February 2009, 97.6% of IPM farmers in November/December 2009, 95.7% of IPM farmers in July/August 2010, 100% of non-IPM farmers in July/August 2010 (more details shown in Figure 5).
Figure 4. Percentage of farmers using non-hazardous Green direct control measures (safe natural source products or biological products) against pests in outdoor tomato production in northern Tanzania interviewed per date. Letters on bars indicate significant differences between farmer groups/years according to the parametric independent samples Welch T tests at p < 0.05.

Figure 5. Percent of farmers using synthetic or natural fungicides/bactericides, insecticides/acaricides or nematicides in outdoor tomato production in Northern Tanzania interviewed per date. Letters on bars indicate significant differences according to the PostHoc multiple comparisons Games Howell test at p < 0.05 following ANOVA.
Between 79.5 and 94.3% of IPM farmers also use natural source pesticides. This is a significantly higher proportion than the 8.6% of non-IPM farmers. The most frequently used natural source insecticides/acaricides included Neem products and soaps.

A larger proportion of farmers applied insecticides/acaricides than fungicides/bactericides. This was particularly true for natural source products, but can also be seen for synthetic products (Figure 5). Among IPM farmers, the proportion using synthetic or natural source insecticides/acaricides decreased slightly over time (by 19 and 9%, respectively). In contrast, the proportion of IPM farmers using synthetic or natural source fungicides/bactericides increased over time, and by 2010 was higher than the proportion of non-IPM farmers using such products (71 versus 60%, and 24 versus 1%, Figure 5). The latter was due to the fact that non-IPM farmers did generally not use natural products for disease control. Hardly, any farmer used nematicides, regardless of being an IPM or non-IPM farmer.

When considering the quantity of synthetic pesticides sprayed per acre, per farmer, per season, the volume

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**Figure 6.** Quantity of synthetic and natural source pesticides sprayed per acre in outdoor tomato production northern Tanzania. Sprays of fermented cow urine and slurry not included. Solid bars = litres; patterned bars = kg. Letters on bars indicate significant differences between farmer groups/years according to the parametric independent samples Welch T tests at p < 0.05.
was shown to have decreased from early 2009 to late 2010 (Figure 6). In 2010, IPM farmers were spraying a lower quantity of synthetic pesticides than non-IPM farmers and then newly trained IPM farmers in 2009 (1.3 L versus 2 L versus 3.1 L/acre per season). However, the amount of natural source pesticides sprayed by IPM farmers increased over the same period (Figure 6). By 2010, IPM farmers were spraying a larger quantity of such products than non-IPM farmers (3.6 L/acre/season versus 1 L). When considering the total amount of synthetic or natural source pesticides sprayed per farmer in kilograms, observed patterns were inconsistent (Figure 6). When considering the frequency of synthetic pesticide sprays, fungicides/bactericides were applied 3 to 3.5 times per tomato season by both IPM or non-IPM farmers and insecticides/acaricides were applied 4.5 to 5 times per season (Figure 7). This resulted in an overall spray frequency for pesticides of about 8 times per season. However, the relative frequency of natural source product applications, particularly soap sprays, increased among IPM farmers whereas the frequency of synthetic product applications decreased (Figure 7). Moreover, the actual products used by IPM farmers changed in favour of less toxic ones (see above).

**Misuse of pesticides**

Regardless of whether the farmers were IPM or non-IPM, only a small proportion used a certain pesticide group against the wrong target, for example an insecticide/acaricide against plant diseases (<3% of farmers), a fungicide/bactericide against an arthropod pest (<3%) or a non-plant protection pesticide (<1%).

**Socio-economic situation**

IPM farmers produced 262 ± 234 crates of tomatoes per acre (= 0.4 ha) per season, and non-IPM farmers produced 201 ± 125 crates, respectively. IPM farmers sold 192 ± 165 crates per acre per season, and non-IPM farmers sold 194 ± 149 crates, respectively. IPM farmers sold 79 ± 13% of their tomatoes on local markets, 2.3 ± 1.1% to supermarkets, 1.6 ± 1.0% to hotels, 2.3 ± 2.1% to central markets and 15 ± 10% in other ways. Non-IPM farmers did usually not sell their tomatoes to supermarkets or hotels; but sold 71 ± 4% on local markets, 3 ± 4.4% to central markets and 26 ± 7.1% in other ways.

The price obtained per tomato crate in target markets (that is, markets identified and targeted by a producer club prior to starting the production of tomatoes) was 12,031 ± 25,867 Tanzanian Shilling (TSH) or 73 ± 160 US Dollar (USD) for IPM farmers between 2009 and 2010. The price obtained per tomato crate in ordinary markets (that is, markets not specifically identified by a producer club prior to starting the production of tomatoes) was 9,825 ± 23,971 TSH or 61 ± 149 USD for IPM farmers, and 9,500 ± 26,924 TSH or 59 ± 167 USD for non-IPM farmers. The income from tomatoes (that is, the tomatoes sold versus tomatoes produced versus production costs without labour) was 946,830 ± 2,215,042 TSH or 5,870 ± 13,733 USD.
USD for IPM/sfarm/season, and 774,803 ± 851,349 TSH or 5,593 ± 12,116 USD for non-IPM farmers. It appeared that IPM farmers profited due to reduced production costs resulting from decreased synthetic pesticide use. 70 ± 46% of interviewed farmers were males. However, IPM farmers were proportionally less males than non-IPM farmers (65 versus 84%) (Table 1). IPM farmers had a proportionally lower school education than non-IPM farmers.

DISCUSSION

It appeared that smallholder farmers who were trained in IPM, provided with a technical guideline and organised in producer clubs more frequently adopted and used non-hazardous preventive or direct measures for arthropod, disease and weed control than conventional farmers during the study time period. The implementation of season-long farmer field schools in east Africa had already been reported as an effective method of training farmers in IPM by others studies (Laurence, 2000), and seemed to have also supported the results in the here-presented case. The same is true for the positive effects of building up producer clubs that can develop small holder farming towards a joined business (James et al., 2010). Solely the combination of farmer training and producer clubs with a joint development of binding technical guidelines for integrated production of vegetables (Boller et al., 2004; Malavolta et al., 2005) was a new aspect in our study.

For example, preventive practices that were introduced and/or adopted by IPM farmers included mulching for water retention and predator enhancement, mixed cropping of garlic or onions between tomatoes to repel pests, use of disease tolerant varieties, use of raised seed beds to avoid soil-borne diseases, or staking of tomato plants for improved aeration and prevention of disease transmission. The longer the farmer had been practicing IPM, the more common it was for them to be using preventive measures, thus indicating that the implementation of a technical guideline requires time and experience.

The raising of seed beds and staking of plants are important measures in the rainy seasons (March to May and November to December in Northern Tanzania), and could be even more widely implemented than currently done. In certain periods, surprisingly, the staking of plants was shown to decrease among IPM farmers, for example when varieties that are preferred by consumers and are traditionally not staked are grown to compete within the market during the rainy season (Djurfeldt et al., 2010). However, even traditional varieties would profit from staking and improved aeration. The opposite pattern was found for the use of mulching, a measure used in the dry season to retain water in the soil (Page et al., 2010). An increasing numbers of farmers appeared to have understood that mulching also prevents weed growth and helps to enhance predators of arthropod pests.

In terms of direct control measures, IPM farmers used more IPM-compatible control measures than non-IPM farmers. For example, Green products used 84% more frequently than by non-IPM farmers. This was likely to have been a result of enhanced knowledge about these practices through farmer training as well the provision of a Green and Yellow list as part of the technical guideline. In addition, farmers belonging to the vegetable producer clubs were required to adhere to the technical guideline so that they could jointly market their tomatoes as IPM produce. The formation of producer clubs is known to be effective for ensuring the implementation of IPM or other sustainable agricultural practices (Fleurt, 1984; Agwanda et al., 2010; Mithoefer and Waibel, 2011). Another factor might have been that there were about 20% more female IPM farmers than female non-IPM-farmers (Table 1). Females might, be prone to use plant protection methods that are less hazardous for the environment and human health than males. Another factor was that certain non-hazardous or less hazardous products were made available during the study time period through regular contacts between farmers, extension officers and agro-input suppliers. This was part of on-going support of the here-reported project. For example, several Neem–based insecticides and mancozeb- or liquid copper-based fungicides were made locally-available. Several Green or Yellow products were already available prior to the project, most likely due to the presence of large scale organic vegetable producing and exporting companies in the region (Mwasha and Leijdens, 2003; Rosinger, 2013). However, many of the surveyed farmers were unaware of their existence and/or how to use them; an issue that was addressed during the project. Nowadays, non-hazardous insecticides/acaricides, such as horticultural oil, liquid soaps, and sprays made from garlic bulbs, onions, mentha, papaya leaf, marigold and flour are used by IPM farmers. This is also the case for the fungicides chlorothalonil + carbendazim, hexaconezole, lemongrass spray and baking soda - horticultural oil sprays. In contrast to the increased use of non-hazardous and Green measures, the use of hazardous pesticides (WHO toxicity Classes I and II) by IPM farmers decreased by over 80% over the study period. This is a significant improvement compared to general common agricultural practices in East Africa (Kaneka et al., 2000; Ngovi et al., 2007). Several hazardous pesticides, such as the Class 1b insecticide dichlorvos, and the Class II insecticides dimethoate/dimethionate, alpha-cypermethrin and other cypermethrins, were totally phased out. With the continued implementation of the technical guideline within the producer clubs, the remaining toxic Class II products were expected to be phased out over the following year (for example, the insecticides deltamethrin, lambda-cyhalothrin, endosulfan, profenofos and chlorpyrifos). This is a big step forward towards the
production of tomatoes that are both safer and healthier for the consumer and environment. It will also contribute towards improved safety for the farmers who often do not wear the recommended full personal protective equipment (Ngovi, 2002; Ngovi et al., 2007). Finally, this is in line with the Tanzanian plant protection regulation that does not allow farmers to buy and use Classes I and II products without special training (Jubilant Mwangi MAFC and Joseph Bukalasa TPRI, 2012, pers. comm.).

Surprisingly, most farmers regardless of whether they were trained in IPM or not, did not misuse pesticides; for example, applying an insecticide/acaricide against a plant disease. Such misuse of pesticides is known to occur across East Africa (Ngovi et al., 2007). This demonstrates a relatively high understanding about arthropod and disease pests and their control options by farmers within the surveyed region of Northern Tanzania. This is particularly encouraging as about 27% of IPM farmers and 4% of non-IPM farmers had no or at least no formal education (Table 1). Such successes are likely a result of the support provided by the extensive system of over 7,000 frontline village extensionists of the Ministry of Agriculture, Food Security and Cooperatives of Tanzania (Dr. Kajigili, Section Extension Services of the Crop Department of MAFC, 2011, pers. comm.), and farmer trainings in IPM through the German agency for technical cooperation (GTZ), and other organisations in the region from the late 1970s to early 2000s (Bohlen, 1978; Kilimo, 2005; ASDP, 2009).

One of the main aims of enhancing and expanding IPM implementation in the project area was to reduce the overall use and reliance on pesticides. However, arthropod pest and disease pressure appeared to be so high that nearly every farmer resorted to the use of synthetic pesticides, regardless of whether they were a practicing IPM farmer or not. Vegetable producers in the African tropics and subtropics are known to face an enormous amount of arthropod and disease pest problems (Dobson et al., 2002; Pesticide Action Network, 2005; ICIPE, 2006). Of these, white flies and mango fruit flies are particularly difficult to control. However, in our survey, between 79 and 94% of IPM farmers used natural source pesticides in addition to synthetic pesticides, as opposed to 9% of non-IPM farmers. In terms of quantity, IPM farmers sprayed a lower volume of synthetic pesticides than non-IPM farmers. The frequency with which IPM farmers sprayed synthetic products also decreased, whereas the frequency with which natural source products, particularly soap sprays, were applied increased. It is worth noting that certain Green products, such as soaps and oils, need to be sprayed more frequently and at higher quantities than synthetic products in order to achieve similar control effects. The intense spraying by IPM farmers could therefore be misinterpreted when assessing rational use of pesticides. Furthermore, soaps, as well as most biological products, are safe to farmers and consumers (Kaoneka et al., 2000; WHO, 2009).

The survey data demonstrated that the longer the farmer had been practicing IPM and producing tomatoes according to a technical guideline, the lower the use of synthetic pesticides (quantity and frequency). Although this study did not aim to investigate the socio-economic situation of farmers in detail, the costs and income data suggest that IPM farmers are not making a loss compared to non-IPM farmers. Our hope was somewhat fulfilled that farmers would profit due to reduced production costs resulting from decreased pesticide use. Consequently, the IPM approach could be sustainable for Tanzania vegetable production, and could become a business as known from other Africa regions (James, et al., 2010).

Conclusion

Training of farmers in IPM, the implementation of a technical guideline and the establishment of producer clubs has led to the production of tomatoes that are likely to be safe for producers, consumers and the environment due to reduced use of hazardous pesticides. Although the survey did unfortunately not address qualitative achievements during the learning processes of farmers, it is anticipated that the here-reported outputs are a result of learning and changing behaviours. Overall, the above also means that the international development projects behind the activities that have generated the here-reported results have been effective and the donor investment has been worthwhile.

Therefore, we can promote, despite some uncertainties in such approaches (Tripp et al., 2005; Erbaugh et al., 2010; Gilbert, 2013), the implementation of season-long tomato farmer field schools in East Africa as an effective method of training farmers in IPM. We can also highlight the effectiveness of establishing vegetable producer clubs (James et al, 2010) as a way of encouraging farmers to produce tomatoes according to internationally recognised standards and empowering them through the joint marketing of their produce.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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Abbreviations: IPM, Integrated Pest Management; WHO toxicity class, toxicity classes of pesticides of the World Health Organisation; MAFC, Ministry of Agriculture, Food Security and Cooperatives of the United Republic

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