Effect of Pesticide Application Rate on Yield of Vegetables and Soil Microbial Communities

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Abstract

Lindane is listed among the Prior Informed Consent (PIC) pesticides, and agricultural uses of lindane have been banned in 52 countries due to its hazardous nature. However, lindane is still widely used in vegetable cultivation in Ghana. The effect of increasing rates of application of lindane (156.0, 244.0 and 312.0 g ha^{-1}), unden (propoxur) (125.0, 187.5 and 250.0 g ha^{-1}), dithane and karate (166.6, 209.8 and 333.3 g ha^{-1}) on garden eggs, okro and tomatoes was studied to find out if it has any advantage that makes its use attractive to farmers despite its ban. Yields of garden eggs were suppressed by all the rates of lindane applied. In tomatoes, lower rates of lindane increased yields whereas the higher rates suppressed yields lower than the control. In okro yields were higher than the control at all levels of lindane applied though yield increments were low. Unden application had the highest effect on garden egg yields followed by tomatoes and least on okro. In the garden egg and tomato treatments, increasing concentration of unden resulted in decreasing yields though yields were higher on the control plots. The optimum unden rate for garden egg and tomato was U20 (i.e. 125.0 g ha^{-1}). Increasing rates of unden on okro did not have any significant effect. Pesticide application had a higher effect on fungal population (50-70% reduction) than on bacterial population in the soil (23.0–38.4% reduction). Dithane suppressed bacteria most whereas karate suppressed fungal population most. Lower levels of chloride residues in tomato fruits corresponded to lower rates of lindane application. Lindane did not have any advantage over the other pesticides as it caused the least increase in yield. It is recommend that farmers are educated on the adverse effects of lindane use, and government enforces the restriction on lindane importation and use in agriculture.

Introduction

Pesticides are used in controlling insect pests, diseases and weeds in agriculture. They are known to increase agricultural production tremendously as these chemicals act on pests that destroy agricultural produce. The behaviour of a pesticide in the environment depends on its stability, physico-chemical properties, the nature of the medium into which it is applied, the organisms present in the soil, and the prevailing climatic conditions (Graham-Bryce, 1981). It has been established that pesticides could become a nuisance if they are misused. Some of the negative effects of pesticide misuse include low crop yield, destruction of soil micro-fauna and flora, and undesirable residue accumulation in food crops (Edwards, 1986).

In advanced countries, strict pesticide regulation and enforcement mechanisms are put in place to ensure their safe use and proper handling. The control schemes further ensure that approval for the sale and use of pesticide is based on scientific data that support its effectiveness against target pests and that it is not unduly hazardous to human health and the environment. Pesticide use in most developing countries is, however, based solely on manufacturer's recommendations. These recommendations, which include data on toxicological and environmental properties of the pesticides, though useful, may not be appropriate under local conditions since they were tested under different agro-climatic and socio-cultural conditions. With the intensification of agriculture and increasing usage of pesticides, the need to study the side effect of pesticides on various soil properties and on the host plant is very crucial.

A survey conducted in vegetable growing areas in Ghana identified lindane, unden, karate and dithane as the most used pesticides by vegetable growers. According to Brown (1978), lindane is used primarily as an insecticidal treatment for hardwood logs and lumber, seed grains and livestock. It is also used as an insecticide for several dozen fruits and vegetable crops and for personal hygiene as a scabicide (EPA, 2002). However, lindane is listed among the Prior Informed Consent (PIC) pesticides, and all agricultural uses of lindane have been banned in 52 countries due to its hazardous nature. Pharmaceutical uses of lindane have also been banned in some countries because it has been found to cause seizures and damage to the nervous system, and also to weaken the immune system (PANNA, 2007). Since lindane is used extensively for agricultural purposes, residues are often found in fruits, vegetables, milk and meat.

Despite the hazardous nature of lindane, farmers in Ghana continue to use the chemical as pesticide on their vegetable crops. The objectives of this study were: (i) to compare the effects of different rates of application of lindane and some other selected pesticides on vegetable yield and soil microbial activity, and (ii) to determine whether lindane has any advantage over the other pesticides that makes its use attractive, despite its ban in agriculture.

Materials and methods

The trial was initiated in the year 2001 with lindane ($C_6H_6Cl_6$), propoxur (unden) ($C_{11}H_{15}NO_3$), karate ($C_{23}H_{19}ClF_3NO_3$) (all insecticides) and dithane ($(C_4H_6Mn_xN_2S_4Zn_y)_z$), a fungicide, at Kwadaso. Selection of pesticides was based on the outcome of a survey conducted within vegetable growing areas in Ghana which identified lindane, unden, karate and dithane as the main pesticides being used by vegetable growers in Ghana, and garden egg, tomato and okro as the most widely used vegetables in Ghana. The experiment was repeated in 2002.

For each vegetable, the experiment was arranged in a split-plot design with the pesticides as the main plot and the rates as the subplots. Each treatment was replicated four times. The varieties of vegetables used were tomato (power), garden eggs (local variety) and okro (local variety). Each plot received a 20-, 30-, and 40-ml portion of each pesticide added to water and made to a volume of 15 litres with water (representing L20 (156 g ha^{-1}), L30 (224 g ha^{-1}), L40 (312 g ha^{-1}) and U20 (125 g ha^{-1}), U30 (187.5 g ha^{-1}), U40 (250 g ha^{-1}), K20, K30, K40 and D20, D30, and D40 for lindane and unden, karate and dithane, respectively).

The pesticide solutions were applied to the assigned plots uniformly on the plants at 2-weekly intervals until harvesting was completed. The plot size was 3 m × 4 m. Tomato and okro were harvested seven times and garden egg five times over a period of one and a half months when the fruits were ready for harvest. The experiment was established on soils of *Nzima* series classified as Haplic Nitisol (FAO, 1990). The soil data taken were soil *p*H, texture, organic carbon, cation exchange capacity, Bray's available phosphorus, soil particle size and exchangeable bases (Table 1) (Jackson, 1974).

TABLE 1

Chemical properties of Asuansi (Ferric Acrisol) soil series (0-20 cm)

Parameter	*Value*
*p*H (soil/H_2O=1:2.5)	5.80
Available phosphorus, mg kg^{-1}	5.00
Total nitrogen, g kg-1	1.50
Organic carbon, g kg^{-1}	14.50
Exchangeable Ca, $cmol_c$ kg^{-1}	8.80
Exchangeable Mg, $cmol_c$ kg^{-1}	4.30
CEC, $cmol_c$ kg^{-1}	14.55
Sand, g kg^{-1}	60.20
Silt, g kg^{-1}	36.00
Clay, g kg^{-1}	3.80

Basal NPK fertilizer (90-60-60) was applied to all plots including the control. Bacteria and fungi populations in the soil were determined by the most probable number method as described by Alexander (1982). Triplicate composite soil samples were taken from each block of pesticide treatment for microbial population analysis. Pesticide (lindane) residue in tomato fruits was determined by quantifying the chloride ions in the fruit extracts by titration with 0.1 *M* $AgNO_3$ solution. A 20-g tomato fruit sample was milled in stainless steel mill and 100 ml distilled water added and filtered. A 10-ml aliquot of the filtrate was taken for titration with 0.1 *M* $AgNO_3$ solution using potassium chromate as indicator (Krasnykh, 1984). The background level (control) and the sample chloride levels were determined. The difference represented the residue level (1.0 ml 0.1 *M* $AgNO_3$ was equivalent to 4.836 mg lindane).

Results

Fig. 1 shows the percentage change in fruit yield over the control. In egg plants, application of lindane gave yields less than the control with yields declining with increasing lindane rates. In tomatoes the yield decline was observed in concentrations higher than L20 (i.e. 244 and 312 g ha^{-1}

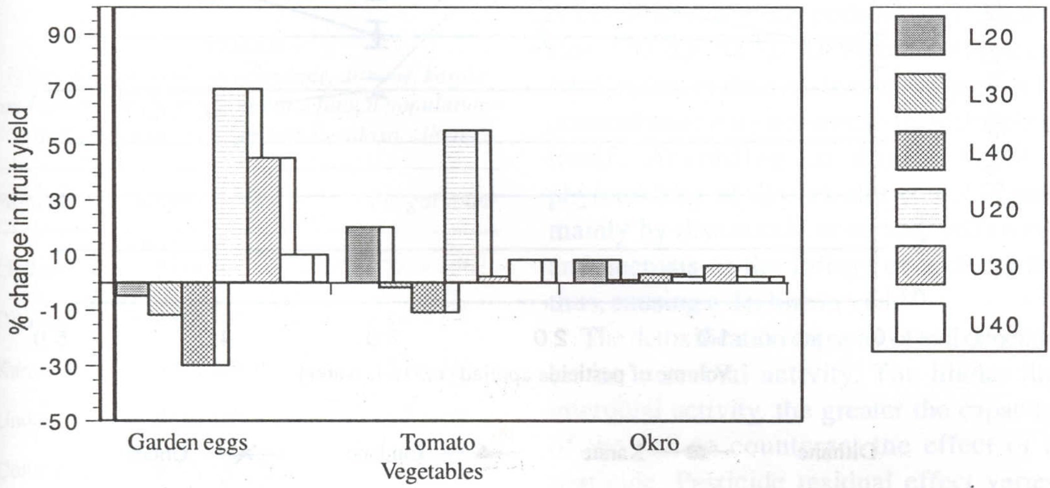

Fig. 1. Changes (%) in fruit yield over control

lindane treatments). Application of 156 g ha^{-1} lindane on tomato and okro gave yields higher than the control. In okro, though there was a decline in yield with increasing lindane rates, the yields did not fall below the control. The effect of lindane treatment on vegetable yields appeared in the following declining order: garden eggs > tomato > okro. Yields declined in all the pesticide-treated plants with increasing concentrations.

Unden application suppressed vegetable yields in the following order: garden eggs > tomatoes > okro. Lower rates of unden (U20 and U30) improved garden egg yields remarkably. In tomatoes only the lowest unden rate (U20) improved yields. There was, however, no improvement in yields in okro. Garden egg yields increased over the control by about 70% in the U20 (i.e.125 g ha^{-1}) treatment and by about 50% in the U30 (i.e.187.5 g ha^{-1}) unden treatment while tomato yields increased by about 60% in the U20 treatment. The higher treatments U40 (i.e. 250.0 g ha^{-1}) gave lower yields.

Fig. 2 shows the effect of the quantity of pesticide applied on garden egg fruit yield. Lindane application reduced garden egg yields with increasing concentration as was observed in the first year of cropping. In the second year cropping there was a trend of slight increase in yield of garden eggs following the application of unden and dithane. Karate did not show any consistency in garden egg yields following the application of increasing pesticide concentrations.

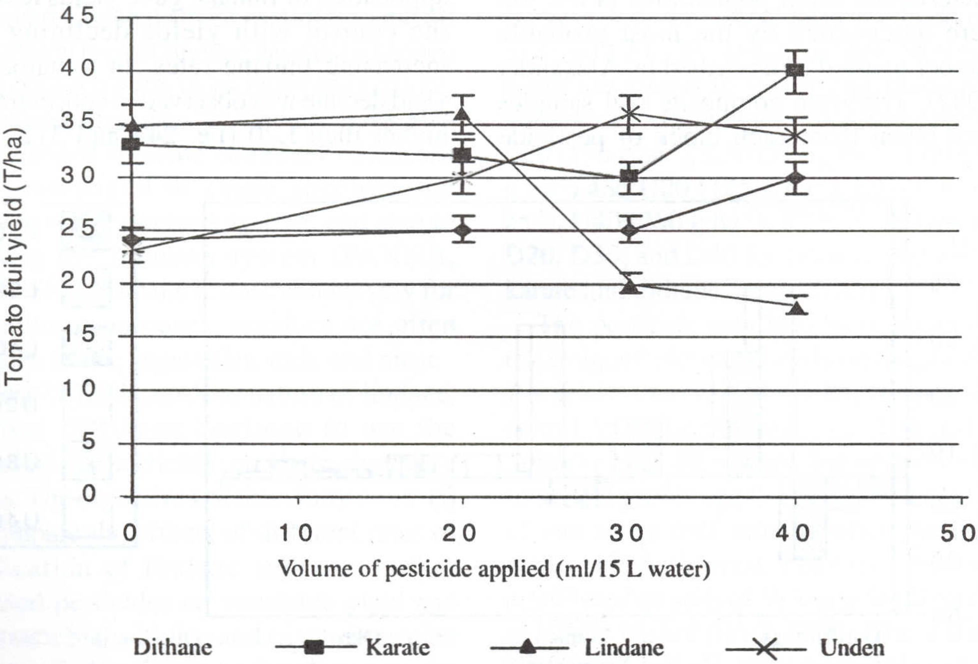

Fig. 2. Yield of garden egg fruits as affected by increasing concentration of pesticide

The effect of pesticide application on microbial population is shown in Table 2. In all the treatments, pesticide application suppressed the population of bacteria and fungi. The highest decline in bacterial population was observed in dithane treatment (38.4%) with the least occurring in lindane and unden treatments (23.0%). Fungal count decline was highest in karate treatment (70.0%) and least in dithane treatment (50%). Generally pesticide application had the higher effect on fungal population than on bacterial population. Table 3 shows chloride ion content of tomato fruits in the lindane treatments. The higher the yield of tomato the lower the chloride ion content of the fruits. Apart from treatment L20 which was significantly lower than the control (background) in chloride concentration, the rest of the treatments were similar in concentration as the background. There was, however, a trend showing increasing chloride concentration with decreasing tomato fruit yields.

TABLE 2

Effect of three pesticides (lindane, dithane, karate and unden) on the bacterial and fungal population in soil grown to egg plants at Kwadaso, Ghana

Pesticide	*Bacterial count*	*Fungal count*
Lindane	5.0×10^5	3.0×10^5
Dithane	4.0×10^5	4.0×10^5
Karate	4.5×10^5	2.5×10^5
Unden	5.0×10^5	2.4×10^5
Control	6.5×10^5	8.0×10^5
$LSD_{0.05}$	0.6389×10^5	0.6475×10^5

TABLE 3

Chloride ion (lindane) content of tomato fruits grown on Nzima *soil series (Ferric Acrisol) at Kwadaso, Ghana*

Treatment	*Chloride (Cl^-) content of fresh tomato fruits %*
Control	0.207
L20	0.177
L30	0.206
L40	0.230
$LSD_{0.05}$	0.029

Discussion

Generally, tomato, garden egg and okro yields were higher at the lower concentrations of pesticide application (Fig. 1), i.e. 156 g ha^{-1} and 125 g ha^{-1} for lindane and unden, respectively. This observation may be due to the fact that increasing pesticide concentration in the soil affected microbial activity, ultimately reducing soil fertility and productivity. According to Bliev *et al.* (1985), application of lower rates (5 and 10 kg ha^{-1}) of hexazinone ($C_{12}H_{20}N_4O_2$) pesticide increased ammonification and decomposition of cellulose in a soddy podzolic soil. Higher rate (20 kg ha^{-1}), however, inhibited nitrification in the soil. Increasing pesticide concentration may become toxic to the plant itself. According to Diallo (1986), phytotoxicity of insecticides is manifested mainly by distortions, scorches, yellowing and necrosis of the foliage or global wilt, thus, causing a decline in yield.

The detoxification capacity of soil depends on its microbial activity. The higher the microbial activity, the greater the capacity of the soil to counteract the effect of a pesticide. Pesticide residual effect varies depending on the dosage. Bliev *et al.* (1985) observed that there were no traces of hexazinone in the soil after 450 days when 5 kg ha^{-1} of the pesticide was applied. By increasing the dosage of the pesticide to 10 kg ha^{-1}, it took 750 days for the pesticide to completely finish in the soil. Regarding soil organisms, it has been shown that insecticides, which are oily in nature, affect soil bacteria considerably. Chlorinated hydrocarbons and carbamates have adverse effects on nitrifying and ammonifying bacteria (Diallo, 1986).

It was expected that traces of lindane in the form of chloride ions would be found in the tomato fruits. In principle, the lower levels of chloride ions in the lindane-treated samples than the control (background) could mean that lindane did not accumulate in the tomato fruits. Lindane application suppressed growth resulting probably in low uptake of the pesticide, thus, rendering the lindane-treated fruits lower in chloride content than the control. In most cases, yields were higher in plants treated to unden than in lindane treatments. This may be due to the nitrogen content of unden which may become available to the plant as a nutrient after decomposition in the soil.

Apart from affecting the environment as poisons, most pesticides used in agriculture in Ghana also affect the crops directly by causing increases in yield at lower rates and decreases in yield with increasing concentrations (e.g. unden and diathane). Others cause decreases in yield irrespective of the pesticide concentration (e.g. lindane). Pesticides could also be lost through leaching, erosion, or photochemical decomposition (Graham-Bryce, 1981).

The pesticides also affect the microbial population of the soil even though micro-organisms are responsible for most of the degradation of pesticides in the soil. Pesticide treatments that gave the optimum yields could be used as optimum rates and, therefore, the recommended rates of pesticides. Thus, the U20 treatment (i.e. 125.0 g ha^{-1} unden) could be recommended for use on garden egg, tomatoes and okro. According to Svetkov (1985), in Germany the acceptable residue concentration of unden is 5, 4, and 3 mg kg^{-1} of salads, cabbages and fruits, respectively.

Conclusion

The yield trends observed so far showed that lower rates of application of pesticides may be more desirable as they reduce the pesticide burden on the environment and are more economical as far as cost of pesticides is concerned. Lindane did not have any advantage over the other pesticides as it caused the least increase in yield. Lindane's continued use in Ghanaian agriculture is, therefore, unwarranted, and could be due to ignorance and poverty, in addition to failure of government agencies to enforce regulations.

A survey conducted by the authors showed that lindane enters the country mostly through cross-boarder trafficking, and is relatively cheaper than other pesticides. Lower rates of unden (125.0 g ha^{-1}) could be applied on garden eggs and tomatoes to improve yields. Chloride concentration in tomato fruits was inversely proportional to the yield and was lowest in the treatment with the highest tomato yield. These results suggest biodilution of pesticide chloride ion in tomatoes (Driscoll *et al.,* 1995). The decline in fungi population in the soil following pesticide application was about twice the bacterial population.

Recommendations

Lindane did not have any advantage over the other pesticides as it caused the least increase in yield. It is banned for agricultural purposes in 52 countries due to its hazardous nature, so its use in Ghanaian agriculture should be discontinued. Government agencies responsible for enforcing the restriction on lindane importation should monitor its entry into the country and ensure that it is used for the intended purpose and not in agriculture. Farmer education on the hazards of lindane use is recommended, while efforts should be made to provide alternative pesticides at affordable prices. Further studies are recommended to establish the most appropriate pesticide rates with minimum effect on the soil microbial activity as well as crop yields.

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