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Full Length Research Paper

Organic soil fertility amendments and tritrophic relationships on cabbage in Uganda: Experiences from on-station and on-farm trials

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Organic soil fertility amendments may have direct or indirect pest management properties through an impact on crop characters and/or the pest's natural enemies. This study was carried out to assess the effect of utilizing market crop wastes (MCW) as soil fertility amendments on tritrophic relationships of cabbage. The study was conducted on-station for three consecutive seasons; and was verified on-farm for one season. Treatments included 1) MCW compost incorporated in soil; 2) Un-composted MCW incorporated in soil; 3) Un-composted MCW on the soil surface; 4) a chemical fertilizer (NPK) incorporated in the soil; and 5) the un-amended control. The treatments were arranged in a randomized complete block design with three replications. The MCW were applied at a rate of 12 tonnes/ha. Data was collected on plant attributes, pest population dynamics of two pest guilds, natural enemies, and cabbage yield. Results indicated that MCW compost amended plants consistently had the highest aphids and diamondback moth infestations; the highest natural enemies' counts and the highest cabbage yield. Correlations revealed that the soil fertility amendments had effects that cascaded to different trophic levels.

Key words: Aphids, diamondback moth, market crop wastes, natural enemies, plant attributes.

INTRODUCTION

It has been shown that the ability of a plant to resist or tolerate pests is grounded, partially, in favourable physical, chemical and biological properties of soil (Luna, 1988); and that farming practices that cause nutrition imbalances can lower plant resistance to pests (Vogel et al., 1993; Magdoff and van Es, 2000). Nutrient fertilization of plants may also have effects that propagate to higher trophic levels leading to higher population densities of insects' natural enemies. Generally, indirect effects on soil- and crop-related properties such as crop stand structure and density, as well as prey availability account for response of natural enemies to soil fertilization (Honek and Holopainen, 1986; Kromp, 1999). A given soil fertility management approach could therefore have direct or indirect pest management properties through an impact on crop characters and the pest's natural enemies. The combined effect could potentially lessen or exacerbate pest infestations. Rejuvenation of soil nutrients and other properties may be achieved through the use of inorganic and organic amendments. Use of inorganic fertilizers by resource-poor farmers is constrained by inadequate supply, unstable prices of agricultural produce, scarce financial resources, and lack of access to credit. For example, fertilizers in Africa cost 2 - 3 times as much as those in Europe, North America, or Asia (Sanchez, 2002). Organic amendments offer a potential soil replenishment strategy, especially in peri-urban areas with the advantage of being near urban areas inundated with huge quantities of market crop wastes (MCW), a resource that is currently being lost to the landfill. Over time, many benefits and advantages accruing from the use of organic amendments over synthetic fertilizers have come to light (Clark et al., 1998; Bulluck et al., 2002). However, beyond documented effects on improved soil structure and nutrient content, less is known about the multi-functional effects of MCW organic amendments, including their effect on crop pests. This study therefore, was

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aimed at understanding the underlying effects of MCW amendments on plant properties, insect pests and the associated natural enemies. One on-farm trial was conducted to validate results obtained on-station.

MATERIALS AND METHODS

The study was carried out for three consecutive seasons (2003B, 2004A, and 2004B; area has a bimodal rainfall pattern with A and B symbolizing first rains (April - June) and second rains (September – November) of the specified year, respectively) at the Makerere University Agricultural Research Institute, Kabanyolo (MUARIK) in Uganda (0°28' N, 32°27' E; 1200 m above sea level). The study was also repeated on a farm 2 km away from MUARIK in 2004B. The average daily rainfall for the area was 22.2, 11.8 and 22.1 mm for 2003B, 2004A and 2004B, respectively. Cabbage seeds (cv. Drumhead) were obtained from a local dealer in agricultural inputs. Cabbage seeds were sown in wooden boxes containing soil previously heat sterilized and passed through a 5 mm sieve, and were transplanted into 7cm diameter plastic pots filled with similarly treated soil. The site's soils were oxisols with a pH 4.56. The fields were tractor ploughed and harrowed one week prior to transplanting the cabbage seedlings. Seedlings were transplanted to the field at a spacing of 60 cm × 60 cm. A randomized complete block design was used in all the trials, with the following treatments: (1) Market crop wastes (MCW) compost incorporated in the soil, (2) un-composted MCW incorporated in the soil, (3) un-composted MCW applied as surface mulch, (4) a conventional chemical fertilizer (NPK) incorporated in the soil, and (5) the un-amended control. Each treatment was planted in plots measuring 10 × 5 m with 2 m alleys in between and was replicated three times. During on-station, for subsequent seasons, treatments were replanted in the same plots used in the first season of the study (2003B). This was aimed at understanding the cumulative effect of the amendments. Samples of MCW were taken from the batch to be used in the experiment at the beginning of each season and were analysed for nutrient composition (ICRAF, 1996). The average nutrient composition of un-composted MCW (per 100 g) was 2.0% N, 0.55% P, 4.94% K, 6.4% Ca and 2.86% Mg. The composted MCW of the same weight had 0.99% N, 0.43% P, 2.2% K, 4.0% Ca and 2.27% Mg. The MCW amendments were applied at the rate of 12 t ha^{-1} whereas NPK was applied at a rate of 70 kg N ha^{-1}, 50 kg P ha^{-1}, and 50 kg K ha^{-1}. MCW were obtained from garbage skips in the markets of Seeta, a suburb of Kampala. Supervised casual labour was employed for sorting, and processing of the wastes. The facilities of a local Non Governmental Organization (NGO), Talent Call, in the town suburbs were used for composting the MCW using the windrow technique (Gordon et al., 2001).

The physical growth attribute leaf area was assessed on 10 plants per plot randomly selected along the two diagonals of each plot. Leaf area was determined for the youngest fully expanded leaf and was obtained by multiplying the length and width of the leaf at the widest part on the plants. This estimation method was found to yield a Pearson's correlation of 0.87 to the actual leaf area (Schellhorn and Sork, 1997). The data on leaf area was collected weekly from 15 days after transplanting (DAT) until head formation.

The study insects were from two feeding guilds; aphids (*Brevicoryne brassicae* L. and *Myzus persicae* Sulzer) (Homoptera: Aphididae) and the diamondback moth, *Plutella xylostella* L. (Lepidoptera: Plutellidae) representing suckers and chewers, respectively. Sampling for cabbage aphids was done weekly on ten randomly selected plants per plot from 15 DAT to head formation. Stems as well as upper and lower surfaces of all the leaves of the selected plants were carefully examined for aphids. Aphids infestation per plant was rated on a scale of 1 - 6 where 1 = no aphids; 2 = 1 - 9; 3 = 10 - 29; 4 = 30 - 59; 5 = 60 - 99; and 6: ≥ 100 aphids. The aphid scale used was not a standard; it was set according to the level of infestation in the field during the experiment. Aphid scores are usually handy in situations of excessive aphid numbers but are usually associated with a little trade off on absolute accuracy compared to individual counts. Also, with scores, transformations are not always necessary unlike in individual count scenarios with the oftentimes-large disparities between data sets. For *P. xylostella*, the same plants used to sample for aphid infestation were used to evaluate the occurrence of *P. xylostella* infestation.

Data were collected by recording the number of larvae and pupae on the whole plants. The same plants used for recording aphids and diamondback moth infestation were used to record the occurrence of predators. Direct observations were used to record the occurrence of ladybird beetles (Coleoptera: Coccinellidae), syrphid flies (Diptera: Syrphidae) and spiders (Arachnida: Araneae). Sampling for insects was usually done between 10.00 to 12.00 h.

At harvest, head quality was determined following the scale employed by Hummel et al. (2002). The scale was of 0 - 5 (0 = no damage; 1 = flame leaf damage; 2 = minimal wrapper leaf damage; 3 = significant wrapper leaf damage; 4 = head damage; and 5 = severe head damage). All heads with a rating ≤2 were considered marketable. For each plot, the total number of marketable heads and their net weight were recorded.

Data analysis

Data were transformed (when appropriate) to achieve homogeneity of variance, using square-root transformation $(X + 0.5)^{1/2}$ for insect counts and percentages (Gomez and Gomez, 1984). Treatment effects were diagnosed using a two way ANOVA (GLM) (SAS; SPSS 16) with season and the soil amendment treatments as the factors; the Student-Newman-Keuls test was used to compare means. The Pearson's two-tailed correlations were also done to test for relationships among variables.

RESULTS

Effect on insect pests

Aphid infestation was significantly affected by the different soil treatments and season (Table 1). MCW compost amended plants generally sustained the highest aphid infestation but this was not much different from the soil incorporated un-composted MCW amended plants. On the other hand, plants amended with un-composted MCW spread on soil surface had aphid levels that were as low as those in the un-amended plots. Aphids were more abundant on-farm than on-station (Table 1). On station, the highest aphid infestation was in season 2 (2004A), a dry and hot season. Diamondback moth infestation was also significantly influenced by the different soil amendments and by season (Table 2). With regard to the amendments, diamondback moth infestation followed a more or less similar trend as that of aphids. In fact, the Pearson's two-tailed correlation between aphid scores and diamondback moth counts was highly significant and positive ($r = 0.622^{**}$, N = 255 and 225, respectively). Diamondback moth infestation was also found to be higher on-farm than on-station (Table 2).

Table 1. Effect of the different amendments and seasons on aphid scores/plant.

Treatment	Season*					
	On-station 2003B	On-station 2004A	On-station 2004B	On-farm 2004B	Mean	$F_{(df\ 3,\ 235)}$
MCW compost incorporated	1.77	3.74	2.32	4.87	3.18a	
MCW un-composted incorporated	2.10	2.63	1.94	4.73	2.85a	
MCW un-composted as surface mulch	1.65	2.23	1.65	3.80	2.33b	
NPK incorporated	1.68	2.18	2.87	4.27	2.75ab	
Un-amended control	1.78	2.13	2.13	3.53	2.39b	
Mean	1.80d	2.59b	2.18c	4.24a	2.70	88.10***
$F_{(df\ 4,\ 235)}$					6.57***	

Means in the same row/column followed by different letters are significantly different (P < 0.001); Aphid score 1 = no aphids; 2 = 1 - 9, 3 = 10 - 29, 4 = 30 - 59, 5 = 60 - 99, and 6: >100 aphids; *in season 2004B the study was done both on-station and on-farm.

Table 2. Effect of the different amendments and season on diamond back moth counts/10 plants/plot).

Treatment	Season*					
	On-station 2003B	On-station 2004A	On-station 2004B	On-farm 2004B	Mean	$F_{(df\ 3,\ 205)}$
MCW compost incorporated	3.25	3.50	4.00	98.35	27.28a	
MCWun-composted incorporated	4.42	1.50	3.58	66.22	18.93ab	
MCW un-composted as surface mulch	3.00	1.92	3.67	40.78	12.34b	
NPK incorporated	3.25	1.08	2.50	67.56	18.60ab	
Un-amended control	2.83	0.92	1.33	31.78	09.22b	
Mean	3.35b	1.78b	3.02b	60.94a	17.27	101.71***
$F_{(df\ 4,\ 205)}$					5.397***	

Means in the same row/column followed by different letters are significantly different (P < 0.001); * In season 2004B the study was done both on-station and on-farm.

Effect on natural enemies

Soil amendments and season significantly affected predator counts (Table 3). Generally, the highest predator counts were found in MCW compost-amended and NPK plots. There were more predators on-farm than on-station; and predator counts were highest in season 3 (2004B) compared to the earlier seasons (Table 3). The Pearson's two-tailed correlation between the insect pests (aphid scores/diamondback moth) infestations and predator counts was highly significant and positive (aphids: predators r = 0.455**, N being 255 and 270 respectively; diamondback moth: predators r = 0.644**, N being 225 and 270 respectively).

Effect on plant performance and yield

Leaf area and yield were significantly affected by treatment and season; yield was also significantly influenced by the interaction between treatment and season (Figure 1; Table 4). Leaf area data was not recorded during season 1 (2003B) of the study. MCW amended plants (in whatever form) were generally superior with regard to plant performance attributes as portrayed by leaf area and yield (Figure 1; Table 4). MCW compost amended plants gave highest yields even though they sustained highest pest infestations. There was an advantage in plant performance as a result of cumulative application of MCW soil amendments as shown in season 3 but the reverse was true for NPK and the un-amended (Figure 1; Table 4). Better yields were recorded on-station than on-farm. There was a negative Pearson's two-tailed correlation between cabbage yield and aphid infestation (r = -0.37**; N= 60, 255 respectively) whereas the correlation between cabbage yield and diamondback moth though negative, was not statistically significant.

Tritrophic relationships

Soil fertility amendments were found to have effects that cascaded to different trophic levels. The different soil amendments had a significant effect on the plant attribute of leaf area (Figure 1). Cabbage leaf area had a highly significant positive correlation (Pearson's) with aphid and

Table 3. Effect of the different amendments and season on predator counts/10plants/plot).

Treatment	Season*					
	On-station 2003B	On-station 2004A	On-station 2004B	On-farm 2004B	Mean	$F_{(df\ 3,\ 220)}$
MCW compost incorporated	1.25	4.00	5.17	9.83	5.06a	
MCW un-composted incorporated	0.83	1.17	2.67	6.75	2.86b	
MCW un-composted as surface mulch	0.67	0.83	1.83	4.83	2.04b	
NPK incorporated	0.67	0.58	7.00	8.83	4.27a	
Un-amended control	0.75	0.83	1.75	4.42	1.94b	
Mean	0.83c	1.48c	3.68b	6.93a	3.23	47.69***
$F_{(df\ 4,\ 220)}$					9.656***	

Means in the same row/column followed by different letters are significantly different (P < 0.001); * In season 2004B the study was done both on-station and on-farm.

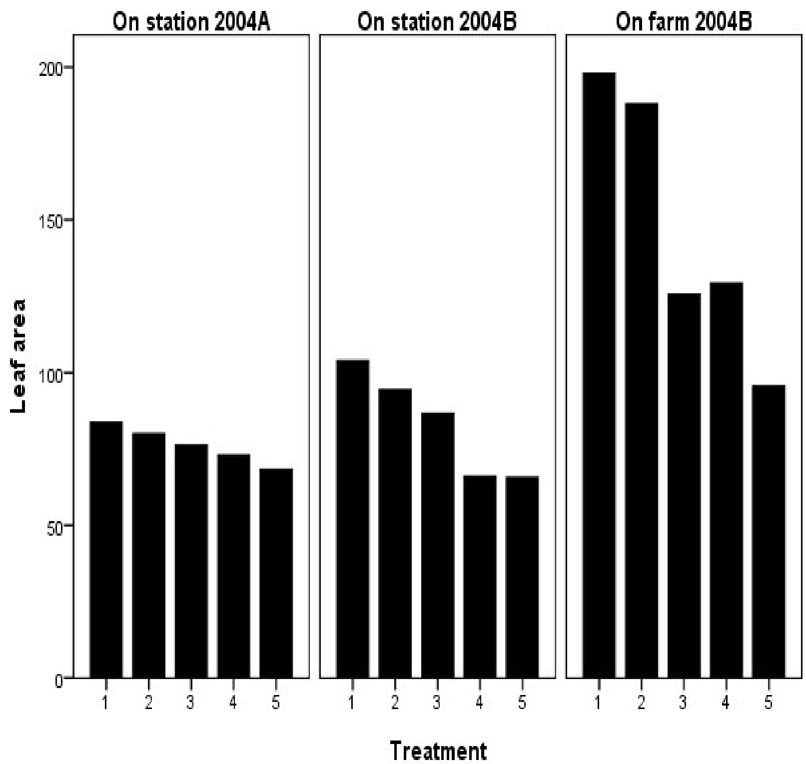

Figure 1. Effect of the different amendments on cabbage leaf area (cm^2) over different seasons. (Where Treatment 1 = MCW compost incorporated in soil, 2 = Un-composted MCW incorporated in soil, 3 = Un-composted MCW on surface, 4 = NPK incorporated in soil, and 5 = un-amended control; 2004A = first rains of 2004; 2004B = second rains of 2004; Statistics: for season $F_{2,\ 30} = 20.49$, $P < 0.001$; for Treatment $F_{4,\ 30} = 3.80$, $P < 0.01$).

diamondback moth infestations (aphids: leaf area r = 0.347*; N = 255 and 45 respectively; and diamondback moth: leaf area, r = 0.412**; N = 225 and 45 respectively) and leaf area also had a significant and positive correlation with natural enemies (r = 0.487***; N = 45 and 270 respectively). As shown earlier, aphid and diamondback moth infestations had a highly significant positive correlation with each other, and with natural enemies (predator counts).

DISCUSSION

Both the aphids and diamondback moth generally responded positively to utilization of soil fertility amendments except for plots where un-composted MCW

Table 4. Effect of the different amendments and seasons on cabbage yield (kgs/plot).

Treatment	Season*					
	On-station 2003B	**On-station 2004A**	**On-station 2004B**	**On-farm 2004B**	**Mean**	$F_{(df\ 3,\ 40)}$
MCW compost incorporated	59.47	34.04	129.67	19.67	60.71a	
MCW un-composted incorporated	59.40	29.03	120.67	17.00	56.53a	
MCW un-composted as surface mulch	42.73	26.41	93.67	17.67	45.12a	
NPK incorporated	34.73	24.15	7.67	15.67	20.55b	
Un-amended control	27.33	17.21	11.00	10.33	16.47b	
Mean	44.73b	26.17c	72.53a	16.07c	39.88	31.762***
$F_{(df\ 4,\ 40)}$					17.147***	

Means in the same row/column followed by different letters are significantly different (P<0.001); *in season 2004B the study was done both on-station and on-farm.

was applied on surface. This positive response has been reported previously (Letourneau, 1988; Jansson et al., 1991). Soil fertility practices can impact the physiological susceptibility of crop plants to insect pests by either affecting the resistance of individual plants to attack or by altering plant acceptability to certain herbivores (Hermes, 2002). The fact that there were fewer aphids in the un-com-posted MCW surface mulch plots was unexpected as the reverse had been observed with the bean aphid (*Aphis fabae*) (Karungi et al., 2006a).

The difference could be due to the different feeding attraction and preferences, with the cabbage aphids feeding on leaves whereas the bean aphid feeds on newly formed stems and leaf petioles (Soroka and MacKay, 1991). Contrary to MCW amendments, cumuli-tive utilization of NPK led to an increase in infestation by the cabbage aphids and a decrease in yield in subsequent seasons. This may be explained by the fact that chemical fertilizers can dramatically influence the balance of nutritional elements in plants, and it is likely that their excessive use will create nutrient imbalances, which in turn, reduce resistance to insect pests (Altieri et al., 1998; Morales et al., 2001).

Pests were more abundant on the farm that was used in this study as compared to the on-station trials. This could have been due to the management techniques uti-lized at the farm over the years that could have increased inoculums for the pests. These being quite specialized pests; continuous cabbage (crucifer cropping) could have caused the problem on-farm, which was not the case on-station.

Plants that sustained more pests were also found to have more predators and the correlation between the two was positive and significant. Mayntz and Toft (2001) also found an increased insect predator density after nitrogen fertilization of plants and explained it as a numeric response to increased biomass at the prey (pest) level. Generally, indirect effects on soil- and crop-related properties such as crop stand density, weed diversity and prey availability account for the response of natural enemies to soil fertilization (Honek and Holopainen, 1986; Kromp, 1999).

Organic (MCW) amendments generally brought about higher yields than NPK. This could be explained by the theory put forward by Altieri and Nicholls (2003) that organic fertility amendments may promote an increase of soil organic matter and microbial activity and a gradual release of plant nutrients allowing plants to obtain a more balanced nutrition and be able to stimulate resistance to insects. This could also explain why MCW compost amended plants gave highest yields even though they sustained highest pest infestations. Organic soil fertility practices can also provide the plants with supplies of secondary and trace elements, occasionally lacking in conventional farming systems that rely primarily on artificial sources of N, P, and K. Moreover, use of MCW soil fertility amendments on cabbage was found to be more profitable and to promote better soil quality than NPK (Karungi et al., 2006b).

For most variables, there was a significant effect from the interaction between treatments (different amendments) and season. This can be explained by the fact that for the three subsequent seasons that were conducted on station, treatments were replanted in the same plots used in the initial season of the study. This implies that there was cumulative effect from the soil fertility amendments.

Conclusion

MCW soil fertility amendments were found to have effects that influenced relationships between trophic levels. Despite a tendency to increase insect pest infestations, utilization of MCW soil fertility amendments enhanced cabbage leaf area and yield, and the cumulative effect on yield was positive; a fact that was converse for the chemical fertilizer, NPK. MCW amended plants were also found to have increased natural enemy counts. These results indicate that MCW amendments have great potential in reducing crop susceptibility to insect pest attack.

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