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THE EFFECT OF POULTRY, CATTLE AND SWINE MANURE APPLICATIONS TO SOIL ON LETTUCE YIELD AND QUALITY AND GROUND WATER CONTAMINATION POTENTIAL

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ABSTRACT

This study investigated the effect that poultry, cattle, swine manures, and artificial fertilizer have on the yield and quality of lettuce (*Lactucasativa* L.). The ground water contamination potential of these fertilizers when applied to calcareous soil was also studied. Lettuce plants were cultivated in pots containing soil amended with either of the fertilizers together with a no-fertilizer control. The amount of fertilizer applied to soil was in line with that used by the lettuce growers in Malta. The experiment, including 20 replicates for each treatment, was set up in a greenhouse and the crop height, width, fresh and dry mass, root length, sap NO_3^- and K^+, and heavy metal content were monitored. The drain water from the pots was analysed periodically for NO_3^- content and salinity. The best crop performance was obtained from poultry manure followed by swine manure, cattle manure and artificial fertilizer. Yield from the control soil was poor and also resulted in a crop containing the highest NO_3^- concentration in the sap. No significant difference was found in sap NO_3^- concentration in plants grown in soil amended with the fertilizers. The heavy metal content concentration in the plants was not significantly different except for Ni, Mn and Cu. The highest NO_3^- leaching was shown in the soil amended with manure, especially with that from poultry. Crops grown on cattle manure showed the highest variation in crop mass and also the lowest yield-to-ground water NO_3^- contamination potential ratio.

Keywords: Poultry manure, Swine manure, Cattle manure, Lettuce, Yield

1. INTRODUCTION

Farm yard manure (FYM) has been used as a fertiliser since ancient times. In soil it does not only serve as a source of important plant nutrients [1] [2] [3], but also contributes to the organic matter content of the soil thus improving its health and sustainability through the improvement of its structure, water holding capacity, cation exchange capacity and microbial activity. The nutrient content and quality of FYM varies and depends largely on its source, its handling and moisture content. The effect of manure application on crop growth and yield has been widely documented and generally an improvement in both has always been noted [4] [5] [6] [7], however, although the benefits associated with its application to arable land are high, this practice can be a significant source of soil and water contamination with NO_3^-. Readily available NH_4^+ from urine present in the manure and from organic N mineralisation, is rapidly oxidised to NO_3^- under aerobic conditions. This can also lead to excess NO_3^- accumulation in leafy crops such a lettuce which might render them unsuitable for consumption [8] [9]. High N accumulation in soil will also result in ground and surface water contamination with NO_3^- [10] [11]. Moreover, FYM generally contains heavy metals such as Cu and Zn, as these metals form an integral part of farm animal nutrition. Under favourable soil conditions these can accumulate in crop and also leach into the ground water together with other mobile ions.

Lettuce is widely cultivated in the Mediterranean island of Malta. The crop is generally grown in open fields and the annual production is around 3.3M kg. The fertilisers used for its cultivation vary from FYM, artificial fertilizer (AF) and a combination of both. The use of FYM as a fertiliser is an important activity on the island as it alleviates the ever growing problem of FYM disposal. The annual solid FYM generation is around 55,000 m^3 and this, together with 366,000 m^3 of slurry from the dairy and swine sector, creates a significant problem when considering a land area of 316 km^2 with a population density of 1,664 km^{-2}. The application of FYM to land is carried out mainly based on tradition, where at the end of summer, the material is added to the soil and ploughed in. The most common FYM used on the island is that coming from the dairy farming sector (CM), however, in the past 30 years or so, poultry manure (PM) and swine manure (SM) stared to be used as well. The application of AF is usually carried out throughout the growing season as part of a fertigation program, depending on the soil type and the crop. Although the application of FYM to land helps with its disposal, there is a rising concern with ground water contamination, and measures have been introduced to regulate this. Ground water in Malta is highly brackish and vulnerable to contamination with NO_3^- [12], where in certain locations, levels exceed 250 ppm.

The objectives of this study were to determine the effect the different types of FYM as used by lettuce growers in Malta have on lettuce yield and quality, together with their NO_3^- and dissolved solids leaching potential. A pot experiment under controlled cultivation conditions

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was carried out. The application of FYM to the soil in pots was based on the application rate adopted by the majority of Maltese lettuce growers.

2. MATERIALS AND METHODS

2.1 Soil and manure sampling

The soil, a calcareous Luvisol with a clay loam textural class, was obtained from the top 20 cm of a field in the location of Mġarr Malta. The FYM was collected from respective farms and the water for irrigation purposes was rain water collected on site from the roof of a greenhouse. The main characteristics of the soil, FYM and irrigation water are shown in Table 1.

Table 1: Characteristics of the soil, manure and irrigation water used in this work

	pH (1:2 $CaCl_2$)*	**EC $_{(1:5)}$ (µS/cm)***	**NH_4^+-N ppm**	**NO_3^--N ppm**	**K ppm**	**P ppm**
Soil	7.7	88	52	66	< 1	36
Water	7.5	218	-	<1	< 1	-
CM	7.8	10,650	1,991	20	1,967	623
SM	7.5	7,250	4,378	90	1,433	2,725
PM	7.5	14,350	5,202	3576	3,500	3,055

Note: * The $CaCl_2$ and the ratios do not apply to the water analyses.

2.2 Pot experiment set up

In order to stay in line with local practice, the FYM was left to dry in air for 3 weeks prior to mixing it with the soil. The dried manure was then crushed and mixed with soil in a ratio that is generally adopted by the majority of the lettuce growers in Malta. The ratios of the mixes are shown in Table 2.

Table 2: Fertiliser applied to each pot based on the amount applied to fields by lettuce growers in Malta

Fertiliser	Application/ha (kg)	Application/pot (g)
Poultry Manure (PM)	45,000	55
Swine Manure (SM)	81,000	100
Cattle Manure (CM)	81,000	100
Artificial fertiliser (AF)	450	0.55 (3 x)

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Each treatment was replicated 20 times in pots measuring 17 cm diameter x 16 cm height. To facilitate drainage, the bottom 2 cm of each pot was filled with gravel that was previously washed thoroughly with distilled water. For each type of FYM, the bulk soil was mixed with it in a large plastic container to produce a mixture as homogenous as possible. From the mixture, 3.5 kg were placed in the pots. Non-manure amended soil was used either for the AF treatment or as no-treatment control (CNT). Artificial fertiliser (N:P:K 12:12:17) was applied to the soil during the growing period by 3 separate applications of 0.55 g each. The first application was carried out when the pots were set on day 1, then on day 35 and on day 42. No AF was added to the FYM-amended soil. The pots were set up in a tunnel-type plastic greenhouse and each pot was placed on a plastic tray to collect drain water following each irrigation session. The pots were planted with one seedling of *L. sativa capitate* on the 21st February and were watered weekly with 50 ml of water for the first 3 weeks, then 100 ml for 1 week, and then 200 ml per week for the rest of the growing period. The plants were harvested on the 13th of April after a growing period of 50 days.

2.3 Crop performance

Throughout the growing season the plant height, measured from the soil surface, and the plant width were recorded on an alternate day basis. After harvesting, each crop was cleared from soil and other non-plant material, washed with distilled and deionised water, and weighed. Five crops from each treatment were chosen at random and dried at 105 ^{o}C for 48 h to measure the dry mass content. The root length of 5 individual plant from each treatment was also recorded.

2.4 Sap NO_3^- and K

The sap NO_3^- and K^+ content was measured by extracting the sap from 5 plants chosen at random from each treatment. The plants were chopped in a blender and the sap was extracted by means of a mechanical press. The NO_3^- content was determined using a calibrated Sentek Ion Selective NO_3^- probe and the K^+ using a calibrated Spectrum Technology K meter.

2.5 Plant heavy metal content

Total heavy metal content was determined in 5 plants selected at random from each treatment. To reduce the possibility of contamination from the environment and the containers, the outer leaves were excluded from the sample. The samples were placed in acid-washed beakers and heated at 105 ^{o}C for 120 min. After drying, crushing and mixing, 1 g of each sample was placed in an acid-washed crucible and heated in a muffle furnace at 550 ^{o}C for 5 h. After cooling 5 ml of 2M HNO_3 were added to the crucibles and left to digest for 20 min. The contents were then topped up to 50 ml with deionised water. Blank controls, without plant material, were prepared in a similar way. Metal analyses (Cu, Zn, Ni, Cr, Ba, Mn, and Pb) were determined using an Agilent MP-AES 4100.

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2.6 Soil and manure analyses

Soil and manure were crushed to pass through a 2 mm plastic sieve and were analysed for available NO_3^-, NH_4^+, PO_4^{3-} and K^+, EC $_{(1:5)}$ and pH. The available NO_3^- was extracted using distilled water in a 1:5 (soil/manure: water) suspension that was shaken on an orbital shaker at 180 rpm for 60 min. The suspension was then centrifuged at 4000 rpm for 10 min and the NO_3^- in the supernatant was determined with a Sentek Ion Selective NO_3^- probe. The same supernatant was used to determine the EC $_{(1:5)}$ and the water soluble K^+. pH was determined in a 1:2 (soil/manure: 0.01M $CaCl_2$) suspension. The suspension was shaken on an orbital shaker at 180 rpm for 60 min and then centrifuged at 4000 rpm for 10 min. The available NH_4^+ was extracted from soil and manure using the same procedure used for NO_3^-, however 1M KCl was used as the extracting solution. Released NH_4^+ was determined using the salicylate-hypochlorite method [13]. P was extracted using the Olsen method [14]. Suspensions of 5:100 (soil/manure: 0.5M $NaHCO_3$) were shaken at 180 rpm for 30 min and the PO_4^{3-} in the supernatant was measured using a modified Ascorbic Acid method [15].

2.7 Leachate analyses

After each irrigation session, if present, water was collected from the pans underneath the pots and analysed for NO_3^-, ECand pH using the methods described earlier.

2.8 Statistical analysis

Data was subjected to analysis of variance (ANOVA) using Sigma Plot statistical package.

3. RESULTS AND DISCUSSION

3.1 Lettuce growth and performance throughout the growing season

The rates of increase in width and height of the lettuce through the growing period are shown in Fig. 1a and 1b respectively, and the mean plant width, height and mass at harvest are presented in Table 3. For both plant width and height, the best performance was obtained from the soil fertilised with PM, followed by SM, CM, AF and CNT treatments. With regards to crop width at harvest, the lettuce from the PM and the SM treated soil were significantly larger than those from the CNT, AF and the CM treated crop ($p < 0.001$). The mean width of the lettuce grown in the CNT soils was significantly smaller than all the other treatments ($p < 0.001$). The harvest mean crop height of the lettuce from the PM treated soil was also significantly larger than those from the CNT, AF and CM crop ($p < 0.001$). The mean height of the lettuce grown in the CNT soils was significantly smaller than the other treatments ($p < 0.001$) except from the AF crop.

PM produced the heaviest crop, followed by SM, CM, AF, and CNT. The difference in fresh mass between the PM and the SM treatment, and between the CM and AF treatments was not

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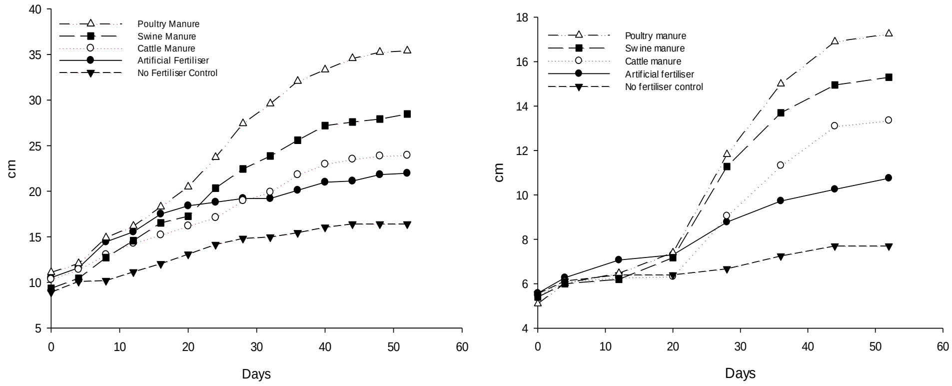
statistically significant. The mean yield of the CNT crop was significantly smaller than the other treatments. Within each treatment, the largest variation in crop mass through the 20 replicates was observed in the CM-treated plants (Fig. 2a), where a range of 24.5 to 258.3 g was recorded. The least variation in mass was shown in the CNT and in the AF-treated crops.

Plant dry mass was also highest in plants grown in soil amended with PM, followed by CM, SM, AF and CNT. Greatest variation in dry mass (Fig. 2b) was again shown in the plants grown on CM followed by those grown in PM. The mean percent dry matter content was highest in lettuce grown in PM, followed by CM, CNT, SM and AF. The greatest variation in percent dry matter was obtained from the soil amended with PM and CM (Fig. 2c).



a b

Fig. 1: The mean width a) and height b) of lettuce plant throughout the growing period in calcareous soil amended with various FYM and AF

Table 3: Post-harvest characteristics of lettuce grown in calcareous soil amended with various FYM and AF.

Plant characteristics	Poultry	Swine	Cattle	Artificial	Control
Width (cm)	35.4	28.5	24.0	22.0	16.4
Height (cm)	17.3	15.3	13.4	10.7	7.7
Fresh mass (g)	289.2	229.5	139.4	123.7	30
Dry mass (g)	51.9	13.7	25.7	7.7	2.9
Dry matter (%)	20.6	7.0	16.8	6.0	9.7
Root length (cm)	34.4	37.6	36.0	38.0	29.3
Sap NO_3^- (ppm)	287	210	293	390	629
Sap K^+ (ppm)	1329	2080	1460	2060	2880
Total Ni (ppm)	6.4	1.0	4.7	0.5	0.5
Total Mn (ppm)	55.4	35.0	31.8	38.9	47.5
Total Cr (ppm)	1.1	0.7	1.2	1.3	0.9
Total Cu (ppm)	3.8	3.9	3.8	4.7	4.7

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Total Pb (ppm)	4.3	3.7	4.2	3.9	5.1
Total Zn (ppm)	6.7	8.0	6.5	11.1	10.1
Total Ba (ppm)	24.9	18.4	24.5	21.3	23.3

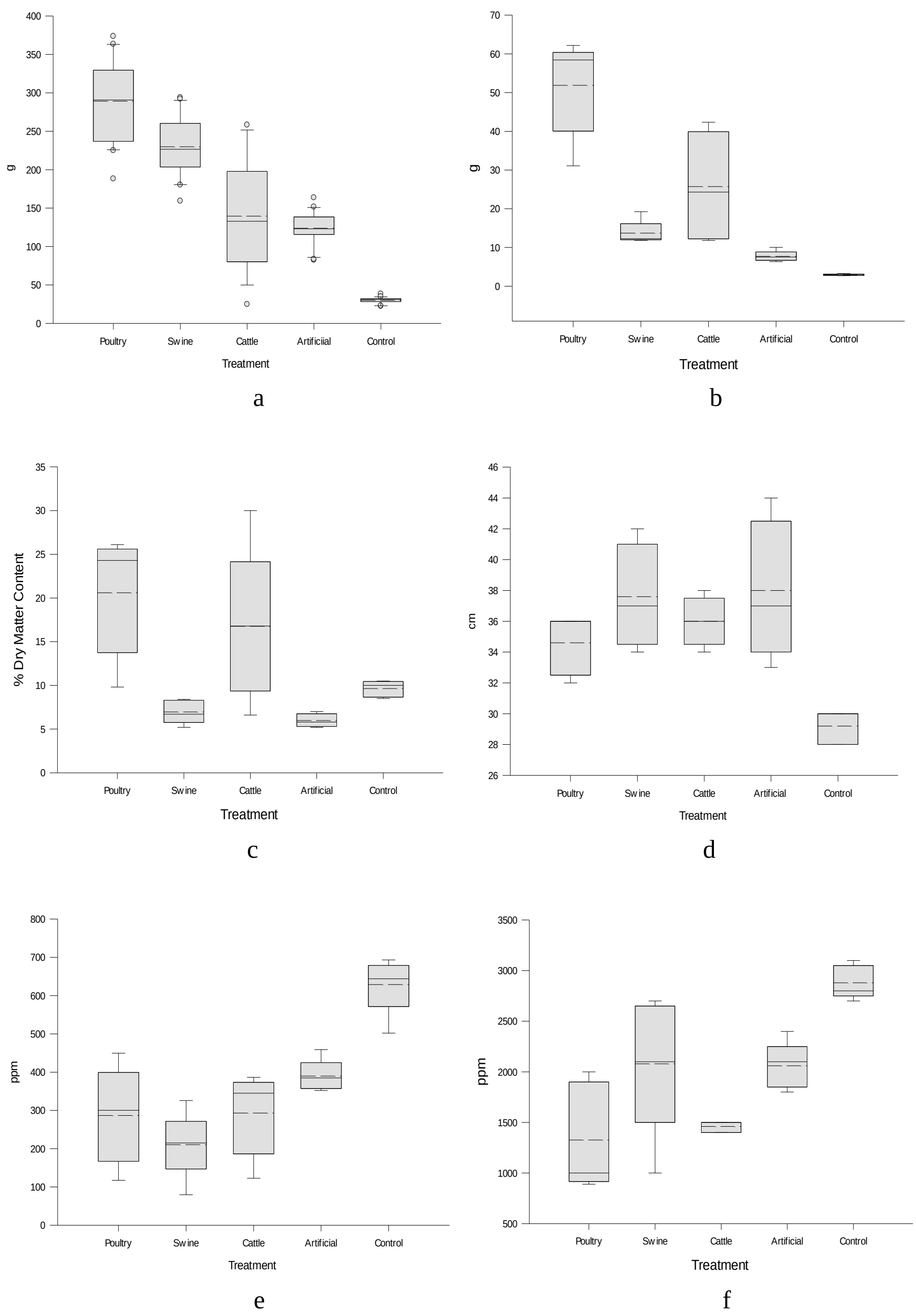

Fig. 2: Post-harvest characteristics of the lettuce grown in soil amended with various FYM and AF. The broken line represents the mean. a) Fresh mass; b) Dry mass; c) Percent dry matter; d) Root length; e) Sap NO_3^-; f) Sap K^+.

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These results show that lettuce cultivated in soil amended with PM and to a slightly lesser extent with SM fared much better in terms of yield than the rest of the treatments. Similar results for PM fertilized lettuce were also reported by other workers [16] [17] [18] [19] [20] [21]. The N requirement for this variety of lettuce in a Mediterranean type climate is modest and averages about 130 kg N ha^{-1} [22]. The readily available N applied through the treatments was similar for PM and SM, and this was higher than in AF and CM. This could explain the difference obtained in the yield. Available K from CM was also very low compared with the rest. The NO_3^--N content in the PM was very high compared with the other treatments and this might explain the slight difference in yield observed between the PM and the SM treated crops. The crop performance in the CNT soil was poor, even though the original combined NO_3^--N and NH_4^+-N content of the soil was 118 ppm, equivalent to around 300 kg N ha^{-1} (20 cm soil depth). The water soluble K in the soil was very low.

The type of fertilizer applied also affected the growth rate. For the first 20 days, the width and height of the lettuce grown in the FYM and AF treated soil increased at the same rate, however after 20 days, the growth rate increased substantially for crops growing in the FYM-treated soil, especially those growing in the soil amended with PM and SM. In these soils, a steady increase in growth was observed for approximately 40 days; with those fertilised by PM showing the highest rate. The lettuce grown in soil amended with AF showed a rapid initial growth however, at around 15 days into the growing period the growth rate started to decline even though AF was reapplied on three occasions during the growing period. Plants grown in the CNT soil also showed a steady growth rate but this was slower than the plants grown in the fertiliser amended pots.

The rapid increase in growth rate shown at around 20 days after transplanting would coincide with rapid nutrient demand, especially N. The high level of nutrients in the PM and the SM is well reflected in the growth rate (Fig.1). The applied N through PM and SM was twice as much as that from CM and much larger than AF. The reapplication of AF was not high enough to produce a growth rate comparable with that obtained by PM and SM. A larger dose of AF would have been required at this particular stage in lettuce cultivation or perhaps better still a larger initial dose. The higher yield and better growth rate obtained in the fertilised crop when compared with the CNT clearly indicates the importance of fertilisers in lettuce production.

The application of fertiliser also affected root development. The root lengths of plants grown in the CNT were significantly shorter than the fertiliser treated crops ($p < 0.001$). The differences between the root lengths of the plants grown with the fertilisers were not statistically significant, however root development was less marked in the PM treated lettuce. Moreira et al. [19] obtained a similar result comparing lettuce root fresh mass from PM and CM treated unmulched soil.

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An interesting observation was the variation in plant mass observed within each treatment. The lettuce grown in CM-amended soil showed the highest variation in crop mass. As no plant disease was noticed that might have led to this high variation, this difference could have been caused by pots not receiving equal amounts of CM fertiliser. CM contain a large amount of bedding material and breaking it down to finer particles was not as easy as it was for the PM and SM. This might have produced a more heterogeneous manure-soil mixture, resulting in pots not receiving a uniform dose of fertiliser. The little variation shown in the AF treated crop supports this argument since AF was added with the irrigation water thus ensuring an even distribution of fertiliser between the pots.

3.2 Plant chemical characteristics

The sap NO_3^- concentration in the crop grown in the CNT soil (Fig. 2e) was significantly higher than all the treatments ($p < 0.001$). In the fertiliser treated crop, the highest NO_3^- level was observed in AF, followed by CM, PM, and the SM. However, the difference was only statistically significant between the AF and SM-treated crop ($p = 0.035$). Sap K^+ (Fig. 2f)was also highest in the CNT crop, followed by the crops grown in SM, AF, CM and PM. Sap K^+ level in the CNT was significantly higher than the rest of the treatment ($p < 0.001$; 0.035(AF), 0.037(SM)). Sap K^+ level in the PM treated plants was significantly lower than that in the SM and AF crops ($p = 0.047$).

The total metal content in the crop is shown in Table 3. The differences between the treatments were only significantly different for Ni, Mn and Cu, ($p < 0.05$), with the crops grown with PM showing the highest Ni content and with those grown in AF and the CNT showing the highest Cu content. Mn and Ba concentrations were relatively high for all the treatments especially for the PM treated plants.

The concentration of NO_3^- and certain metals in the crop could be of significant concern from a health aspect and also from a taste aspect. A portion of ingested NO_3^- is converted into NO_2^- which could be toxic. The concentration of sap NO_3^- and K^+ were significantly higher in the CNT plants. These plants were significantly smaller than the rest, however their average percentage water content was 90 %; greater than that of the PM and CM crop. The higher concentration of sap NO_3^- and K^+ is therefore the result of plant size rather that plant water-to-plant mass ratio, as a larger volume of water would result in a more dilute concentration. Considering the mean fresh mass and dry matter content, the consumption of 100 g of lettuce crop from the CNT pots would result in ingesting approximately 57 mg of NO_3^-, compared to 20 mg when consuming SM-grown crop, and 24 mg from both the PM and the CM-grown crop. By comparison, the ingestion of NO_3^- from 100 g of AF treated lettuce would result in approximately 37 mg NO_3^-. The acceptable total daily intake of NO_3^-, established by the European Commission Scientific Committee on Food is 3.7 mg kg^{-1} of body weight.

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3.3 Drain water analyses and potential NO_3^- and salt leaching

In order to assess the potential ground water contamination from the different treatments, the drain water was collected on five occasions following irrigation, and analysed for EC, pH and NO_3^-. The volume of water that drained from each treatment following an irrigation session is shown in Fig. 3a, and the cumulative volume in Fig. 3b. During the first 20 days of the growing period, the drain volume collected from all treatments was very similar. After 20 days, it increased substantially from the CNT, AF, and the CM-treated soil but the increase was less from the PM and the SM-treated soil. After 30 days the drain volume started to decrease for all the treatments, increasing sharply for PM and SM at day 40. At the end of the growing period, the cumulative mean volume of water collected (Table 4) was highest from the CNT followed by AF, CM, SM and PM. This variation in drain water volume during the growing period is a function of the growth rate of the crop and the climatic conditions. The relatively lower drain volume collected at day 25 from the PM and SM treatments reflects the rapid growth rate of the crop in these treatments, shown in Fig. 1. Rapid growth resulted in more water uptake. After day 33, as the growth rate was highest for all treatments, the drain volume decreased. This decrease also coincided with an increase in ambient temperature leading to an increase in evapotranspiration.

Table 4: Cumulative drain water volume and quality from the soil amended with various FYM and AF.

Treatment	Poultry	Swine	Cattle	Artificial	Control
Total volume (ml)	352	527	589	687	800
Total NO_3^- lost (mg)	143.4	71.7	132.6	14.9	6.9
Dissolved solids (mg)	326	352	262	198	211

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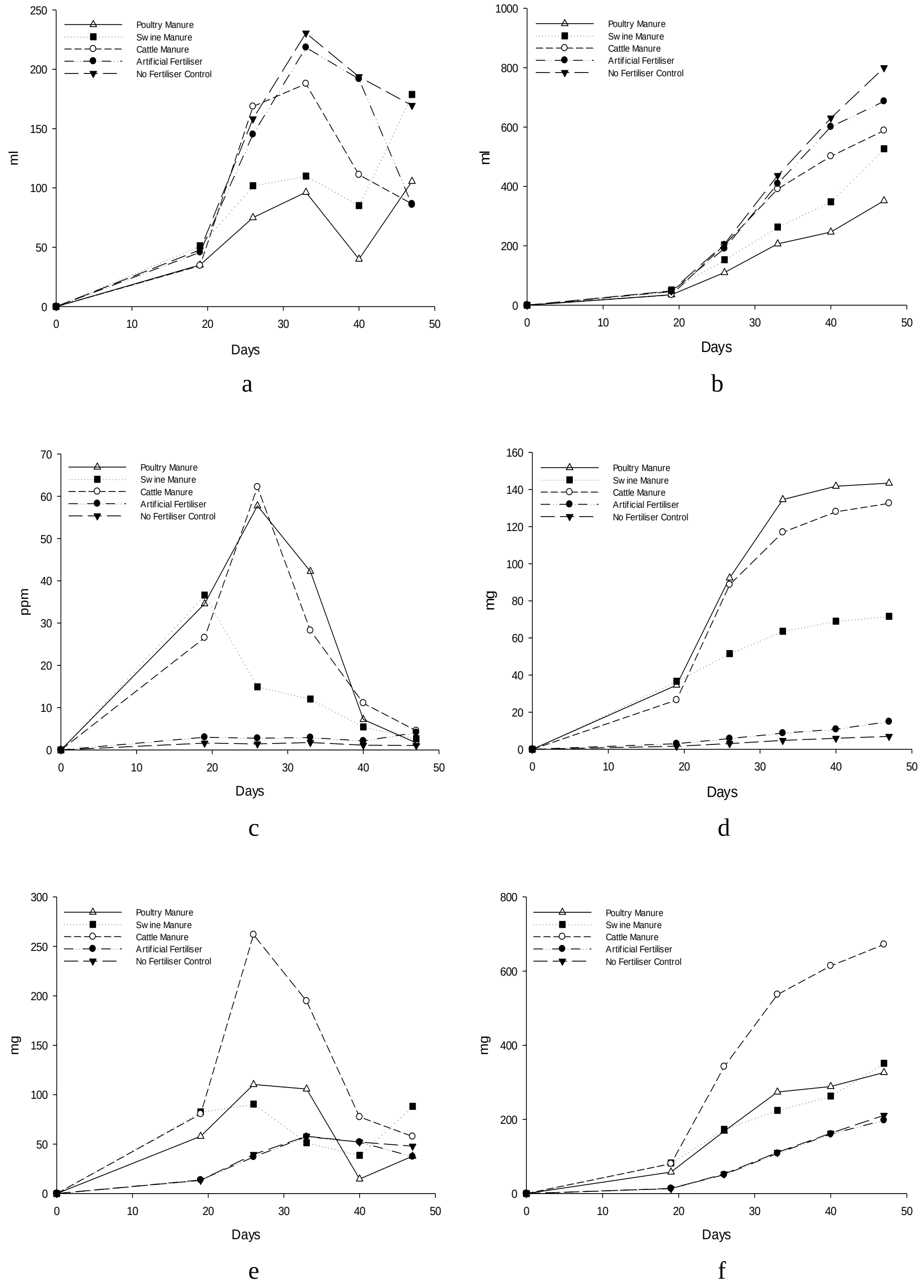

Figure 3: Volume and characteristics of water drained during the growing period from the soil amended with various FYM and AF. a) Volume of drain water; b) Cumulative volume of drain water; c) NO_3^- loss; d) Cumulative NO_3^- loss; e) Dissolved solids f) Cumulative dissolved solid.

Following each irrigation session, the loss of NO_3^- through leaching varied between the treatments (Fig. 3c). The leaching of NO_3^- and other dissolved solids was highest from the soils that were amended with the FYM. Highest rate of NO_3^- leaching occurred from the PM and the CM-treated soil, followed by the soil amended with SM. The loss from the AF and the CNT -treated soil were relatively much lower, reflecting the low application rate of AF and the no-treatment control. Peak leaching occurred at day 20 for the SM and at day 26 for the CM and the PM, after which a decline in NO_3^- loss was noted. This decline also coincides with the stage of rapid growth of the lettuce crop where N and other nutrient uptake will be at its maximum. The cumulative NO_3^- loss from the soils was highest from the PM and CM-treated soil, followed by the SM, AF and CNT soil (Fig. 3d). The leaching pattern of soluble solids was very similar to that of NO_3^-loss, peaking at around day 26 for the FYM-treated soil and decreasing thereafter, only to increase slightly for the SM treated soil close to harvesting (Fig. 3e). The highest loss of dissolved solids was observed from the CM soil. For the AF and the CNT soils, the maximum loss occurred at day 33 following which a decrease was noted. The cumulative loss of dissolved solids was highest from the CM-treated soil (Fig. 3f, Table 4) followed by the SM, PM, AF and the CNT soils. The pH of the drain water from all the treatments varied between 7.7 and 8.0 with no significant differences between the treatments.

The mean NO_3^- losses from each treatment were PM (143 mg), CM (132 mg), SM (17 mg), AF (3 mg) and the CNT (1.6 mg) per pot, suggesting that in this particular soil, these fertilisers, when applied at these rates, have the potential of contaminating the groundwater with 148, 136, 18, 15 and 7 kg of NO_3^- respectively from each hectare of treated soil. Worth mentioning is that despite the fact that the yield of the lettuce grown in the CM-amended soil was lower than that grown in the PM and SM treated soil, the potential for ground water contamination from CM was at par with that from PM and also higher than that from SM. Moreover, the mean yield from AF treated crops was similar to that from CM treated crops but then the risk of groundwater contamination from AF was much lower. The pattern of the leaching water salinity complemented that of NO_3^-, with CM being the most polluting in this case. Considering the overall yield and yield variability, these results might suggest that CM might be the most polluting manure compared to the rest.

4. CONCLUSION

This work has shown that lettuce crop grown in soil amended with FYM had a better growth rate and yield than that grown in soil amended with AF. The use of PM and SM produced the highest yield on a fresh mass basis compared to the other FYM treatments, with CM being the lowest and the treatment showing a significantly large variation in crop mass. With regards to NO_3^- presence in the sap of the product, no significant difference was obtained between the treatments except for the CNT. The level of K^+ in the crop grown in PM-treated soil was significantly lower than in the rest of the treatments. The highest threat to ground water contamination with N and other dissolved solids however resulted from the use of PM

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and CM. Moreover, soil amended with CM showed the lowest yield-to-NO_3^- leaching potential ratio. Considering yield and ground water contamination, SM could be the best treatment to consider, as it produced a high yield with relatively low NO_3^- contamination potential to the water table. CM might not be the best choice due to high variability in crop mass and low yield-to-pollution potential ratio. Furthermore, in the case of FYM applications, NO_3^- and dissolved solids leaching was highest before the crop's rapid rate of growth. Due to lack of direct control on nutrient availability from manure, this fertiliser does more damage to ground water resources than AF. Manure in Malta and in most countries is applied before planting and the availability of the nutrients are dependent on climatic and soil factors. The right quantity of readily available AF applied at the right time will produce a better yield with lower ground water pollution.

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