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ORIGINAL PAPER

Effect of livestock manures on the fitness of house fly, *Musca domestica* L. (Diptera: Muscidae)

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Abstract The house fly, *Musca domestica* L. (Diptera: Muscidae) is one of the major pests of confined and pastured livestock worldwide. Livestock manures play an important role in the development and spread of *M. domestica*. In the present study, we investigated the impact of different livestock manures on the fitness and relative growth rate of *M. domestica* and intrinsic rate of natural increase. We tested the hypotheses by studying life history parameters including developmental time from egg to adult's eclosion, fecundity, longevity, and survival on manures of buffalo, cow, nursing calf, dog, horse, poultry, sheep, and goat, which revealed significant differences that might be associated with fitness costs. The maggots reared on poultry manure developed faster compared to any other host manure. The total developmental time was the shortest on poultry manure and the longest on horse manure. The fecundity by females reared on poultry, nursing calf, and dog manures was greater than on any other host manures. Similarly, percent survival of immature stages, pupal weight, eggs viability, adults' eclosion, survival and longevity, intrinsic rate of natural increase, and biotic potential were significantly higher on poultry, nursing calf, and dog manures compared to any other livestock manures tested. However, the sex ratio of adult flies remained the same on all types of manures. The low survival on horse, buffalo, cow, sheep, and goat manures suggest unsuitability of these manures, while the higher pupal weight on poultry, nursing calf, and dog manures suggest that these may provide better food quality to *M. domestica* compared with any other host manures. Our results point to the role of livestock manures in increasing local *M. domestica* populations. Such results could help to design cultural management strategies which may include sanitation, moisture management, and manure removal.

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Introduction

The house fly, *Musca domestica* L. is one of the major pests of both confined and pastured livestock worldwide. They cause nuisance, spoil food, and act as a vector of medical and veterinary pathogens (Graczyk et al. 2002; Förster et al. 2007; Palacios et al. 2009). The larvae of *M. domestica* may act as myiasis-producing agents in animals, thus leading to economic loss in agronomic livestock (Sehgal et al. 2002). The practice of intensive animal farming coupled with high temperature, humidity, and quantities of manure could provide ideal environments for the development and rapid expansions of *M. domestica* populations (Learmount et al. 2002). Rapid expansion of *M. domestica* in animal units could cause stress to animals and farmers, transmit diseases, and lead to other economic problems, such as contamination of milk in dairies and spotting of eggs in poultries. Expanding urbanization in rural areas and public health concerns about flies associated with livestock facilities often result in neighborhood confrontation and/or even litigation (Kaufman et al. 2010). Although insecticides could reduce *M. domestica* populations, the option is very limited because of insecticide resistance problems (Scott et al. 2000) and ill effects to humans, farm animals, and nontarget organisms (Siriwattanarungsee et al. 2008). These problems emphasize the need for alternative management strategies for *M. domestica* populations, without harming the environment.

Behavioral manipulation is an important insect pest management tool markedly adopted in the last 30 years in an attempt to lessen dependence on synthetic chemicals (Foster and Harris 1997). Deterrent and attractant properties, for example, of feeding materials to manipulate the behavior of pests and natural enemies are typical examples (Jermy 1990; Aluja and Boller 1992); however, the success of such strategies depends on the detailed knowledge of how these feeding materials alter life history and behavior (Foster and Harris 1997). For instance, the quality of feeding material could affect body size, which may affect fitness of insects (Awmack and Leather 2002).

Several researchers have evaluated the effect of livestock manures on *M. domestica* development (Fatchurochim et al. 1989; Hogsette 1996; Farkas et al. 1998; Cook et al. 1999; Mullens et al. 2002; Patricia and Claudio 2008); however, to the best of authors' knowledge, no one explored the effect of various livestock manures on intrinsic rate of population increase, biotic potential, and fitness of *M. domestica*. These fitness parameters usually include high fecundity, shorter developmental time, high pupal weight, increased survival rate, and longevity (Saeed et al. 2010). In the present study, we have explored the effect of different livestock manures on the fitness of *M. domestica*. The results presented here can therefore help us to plan manure management strategies in order to reduce *M. domestica* populations and improve the quality of life of the people residing in and/or around livestock facilities.

Materials and methods

Breeding of *M. domestica*

The adults of *M. domestica* were collected from a livestock farm from Multan (30°12′0″ N, 71°25′0″ E) and brought to the laboratory. The adults were maintained in mesh cages with the provision of diet composed of powdered milk, sugar, and water while the larvae were reared on a paste of bran, grass meal, yeast, sugar, and powdered milk (40:20:10:3:3, by weight) (Bell et al. 2010). The insects were colonized at 25±2°C with a photoperiod of 16 L:8D at 65±5 % relative humidity.

Livestock manures

The test manures used in the experiments were of buffalo, cow, nursing calf, dog, horse, poultry, sheep, and goat. The buffalo and cow manures were collected from a dairy farm where the diet was based on crop residues and fodders including mott grass (*Pennisetum purpureum*), berseem (*Trifolium alexandrinum*), and lucern (*Medicago sativa*). The nursing calf manure was collected from a dairy farm where they were fed with whole milk. The dog feces were obtained from animals fed on meat and meat by-products. The goat, sheep, and horse manures were collected from their respective stables feeding on grasses including bermuda grass (*Cyanadon dactylon*)*,* rye grass (*Lolium multiflorum*), and elephant grass (*Pennisetum purpureum*). Poultry litter was collected from broiler poultry farm where the diet was based on fishmeal, blood meal, soya bean meal, course or broken grains of wheat, maize, millet, rice, sorghum, pulses, and different vitamins. We used the manures of those animals which are preferably reared in the livestock after consultation with local livestock farmers.

The manure of each animal was collected within 3 h after it had been excreted by the respective animal. The moisture contents of the manure were determined by following the procedure of Farkas et al. (1998). Briefly, 5-g sample of manure was dried at 103°C for 3 h and then reweighed, and the weight differences were brought to average. The manures were then adjusted to the moisture contents by either drying or adding necessary amount of water. In order to destroy the presence of dipterous larvae or other arthropods therein, the collected manures were frozen at −20°C for 24 h (Farkas et al. 1998).

Development and survival of *M. domestica*

Before starting the experiment, the population of *M. domestica* was reared on each host manure for three generations (from eggs to adults' eclosion) to adapt new hosts and to remove maternal effects (Lacey 1998). The development of immature *M. domestica* was checked by following the methodology of Patricia and Claudio (2008) with some modification. Briefly, 100 g manure (≈24 h old) of buffalo, cow, dog, goat, horse, poultry, sheep, and goat was placed in a 500-ml beaker and infested with 30 neonatal *M. domestica* larvae (<12 h old) with the help of camel hair brush. The beakers were then placed in insect-free mesh cages to avoid oviposition of flies due to substrate attraction. In order to avoid manures from crusting, moisture of the infested manures was maintained as described by Farkas et al. (1998). The duration of larval period, pupal period, total development time (first instar to adults' eclosion) and survival percentage were recorded to the nearest half day. The laboratory conditions during experiment and data recording were 25±2°C with a photoperiod of 16 L:8D at 65±5 % relative humidity, and the experiment was replicated ten times.

Reproduction of *M. domestica* on different livestock manures

Ten pairs of newly emerged adults from each type of host manure were paired in separate cylindrical plastic jars (23× 35 cm) with a larval medium as stated above. The adults were fed on 1:1 sugar and powdered milk, and the number of eggs were counted for each individual after every 12 h up to 25 days. The eggs of flies were maintained at 25±2°C with a photoperiod of 16 L:8D and 65±5 % relative humidity. The eggs hatch in about a day (Pastor et al. 2011); however, in our experiment, the eggs were given 3 days to hatch and then the number of eggs hatched was counted. The data of all the studied life history parameters were analyzed using Statistix 8.1v (Analytical Software 2005), and means were compared by Tukey's Honestly Significant Difference (HSD) test.

Growth rate

In order to study growth rate, 50 randomly selected first instar larvae were taken from the population reared on each type of livestock manure, weighed, and batches of 10 larvae were placed separately in 250-ml glass beakers provided with 50 g fresh manure as described above. Pupation was recorded after every 12 h. Pupae were removed and weighed to calculate the mean relative growth rate (MRGR) using the following equation:

$$\mathrm{MRGR} = [\ln \cdot W_2 - \ln \cdot W_1] \div T$$

where W_1=initial larval weight (L1), W_2=pupal weights (in milligrams), and T=time (days) from initial larval stage to the pupal stage (Radford 1967).

Intrinsic rate of natural increase and biotic potential

The net replacement rate (R_o) and intrinsic rate of natural increase (r_m) were calculated by using the equations as follows:

$$R_\mathrm{o} = (n \times l_\mathrm{e} \times l_\mathrm{a}) \div 2$$

where n=mean number of eggs per female, l_e=fraction of fertile eggs, l_a=fraction of eclosing adults, and 2=sex ratio coefficient (Birch 1948), and

$$r_\mathrm{m} = (\ln \cdot R_o) \div T$$

where R_o=net replacement rate and T=total developmental time (Birch 1948). The biotic potential was calculated using the following equation:biotic potential=log fecundity ÷ total development time (Ahmed and Wilkins 2001).

Results

Effect of livestock manures on different life history traits of *M. domestica*

Livestock manures had significant impact on the developmental times from egg to adult's emergence (Table 1; F=41.9; df=7, 72; P<0.001). The larvae reared on the manures of poultry, nursing calf, and dog developed faster (9.27, 10.02, and 10.38 days, respectively) compared to the other livestock manures (P<0.05); in contrast, the larvae reared on horse and sheep manures took longer time to develop (13.45 and 12.68 days, respectively). There was no significant difference in the mean developmental time on buffalo and cow or sheep and goat. The pupal weight was significantly different on different livestock manures (Table 1; F=373; df=7, 72; P<0.001). The pupae obtained from poultry and nursing calf manures were heavier (16.89 and 16.56 mg, respectively) than those from any other types of manure (P<0.05); conversely, the pupae obtained from horse manure were lower in weight (11.58 mg). There was no significant difference in the weight of pupae obtained from nursing calf and dog, or sheep and goat. Moreover, poultry and nursing calf manures had maximum percent survival (larvae converted to pupae) (Table 1; F=19.5; df=7, 72; P<0.001).

Adults' eclosion, sex ratio, fecundity, and longevity

Livestock manures significantly affected adults' eclosion (Table 1; F=14.1; df=7, 72; P<0.001). The maximum percentage of adults eclosed was observed from *M. domestica* reared on poultry manure followed by nursing calf and dog manures (87, 81, and 79 %, respectively) while minimum percent eclosion was recorded on horse, cow, and sheep (64, 70, and 70 %, respectively; Table 1). There was no significant effect of manures on sex ratio (F=0.37; df=7, 72; P>0.05). The mean numbers of eggs laid by the females developed on different types of manures were significantly different (Table 1; F=248; df=7, 72; P<0.001). The females reared on poultry and nursing calf manures laid the highest number of eggs (443 and 435 eggs, respectively) in comparison to those who reared on horse manure which laid the least number of eggs (307 eggs). There was no significant difference in fecundity on sheep and goat (49.8 and 48.5 eggs, respectively; Table 1). Livestock manures had also a significant impact on egg viability (F=82.2; df=7, 56; P<0.001). The mean number of eggs hatched on poultry and nursing calf manure were higher (84.7 and 79.8 %,

Table 1 Effect of livestock manures on different life history traits of *M. domestica*

Manure	Larval duration (days)	Pupal duration (days)	Total developmental time (days)	Pupal weight (mg)	Percent survival	Adult eclosed (%)	Sex ratio	Fecundity	Egg hatching (%)	Longevity (days)	
							Female:male			Male	Female
Poultry	4.59±0.09 e	4.68±0.13 d	9.27±0.18 f	16.89±0.11 a	91±1.42 a	87±2.37 a	1:1.04±1.2 a	443±2.40 a	84.7±1.56 a	33.6±2.87 a	36.4±2.48 a
Nursing calf	5.05±0.21 de	4.97±0.12 cd	10.02±0.26 ef	16.56±0.11 a	86±1.05 a	81±1.39 ab	1:1±1.06 a	435±3.55 a	79.8±1.53 ab	28.0±2.07 ab	28.4±1.57 bcd
Dog	5.37±0.21 cde	5.02±0.11 cd	10.38±0.21 de	16.09±0.12 b	84±1.42 ab	79±1.86 abc	1:1.04±1.14 a	412±2.55 b	76.5±1.40 b	26.6±1.91 ab	27.6±2.22 bcd
Cow	5.68±0.14 cd	5.33±0.11 bc	11.01±r0.17d	15.16±0.12 c	77±1.72 cd	70±2.41 d	1:1±1.17 a	385±2.65 c	60.8±1.36 c	26.4±3.2 ab	28.2±1.93 bcd
Horse	7.62±0.22 a	5.83±0.14 ab	13.45±0.24 a	11.58±0.10 e	70±1.35 d	64±1.32 d	11.04±1.24 a	307±2.57 e	55.3±1.31 cd	21.6±0.92 b	22.2±1.46 d
Buffalo	5.92±0.15 c	5.40±0.09 abc	11.32±0.13 cd	15.26±0.11 c	78±1.81 bc	72±1.80 bcd	1:1±1.45 a	400±3.02 b	57.5±1.24 c	27.2±2.88 ab	28.8±0.97 bc
Sheep	6.87±0.31 ab	5.82±0.11 ab	12.68±0.33 ab	12.69±0.07 d	75±2.06 cd	70±1.95 d	1:1±1.61 a	362±2.61 d	49.8±1.98 d	26.8±1.82 ab	30.4±2.58 ab
Goat	6.12±0.14 bc	5.88±0.12 a	12.00±0.16 bc	12.97±0.08 d	75±1.87 cd	71±2.27 cd	1:1.04±1.95 a	360±3.16 d	48.5±1.95 d	23.2±1.46 b	25.6±1.07 cd
HSD 5 %	0.86	0.52	0.95	0.45	7.00	9.00	0.27	13.00	6.96	7.34	8.60

Means sharing the same letters within a column are not significantly different (P>0.05; Honestly significant difference test [HSD], Statistix 8.1). The life history parameters were studied at 25±2°C with a photoperiod of 16 L:8D at 65±5 % relative humidity

respectively) while minimum percentage egg hatching was recorded on goat and sheep (48.5 and 49.8 %, respectively; Table 1). The longevity of adult flies reared on poultry manure was greater (33.6 and 36.4 days for male and female, respectively; Table 1) than on any other type of host manure (F=4.89; df=7, 32; P<0.001 for males; F=9.87; df=7, 32; P<0.001 for females).

Intrinsic rate of natural increase biotic potential and mean relative growth rate

The results revealed that intrinsic rate of natural increase and biotic potential of the flies reared on poultry manure were maximum, followed by nursing calf and dog (Table 2). Moreover, the mean relative growth rate was also maximum on poultry manure compared to any other manure tested (F=40.8; df=7, 32; P<0.001; Fig. 1). The association between intrinsic rate of natural increase and mean relative growth rate of flies was significant (r=0.74, P<0.05) while the association between intrinsic rate of natural increase and biotic potential was highly significant (r=0.99, P<0.001).

Discussion

The life history traits of a particular insect could vary on different types of feeding materials; the factors determine the host suitability for omnivorous hosts. Rapid developmental time and higher reproduction rate of insects on a particular host indicate greater suitability of a feeding material (Awmack and Leather 2002). The development and reproduction rates point important clues regarding the host ability to help complete life cycle of insects. These data, however, should be linked to other factors like mortality before any conclusions are drawn with reference to the host fitness (Saeed et al. 2010). In the present study, the rate of development of *M. domestica* varied on different types of livestock manures. The longest developmental time was on horse manure but was shortest on poultry, nursing calf, and dog manures. The development of insects could vary in different types of livestock manures (Patricia and Claudio 2008) owing to the variation in nutritional and phagostimulant factors (Myers et al. 2008). The poultry, nursing calf, and dog manures proved better hosts for *M. domestica* as the larval duration was shorter on these hosts. Rapid development on a specific host could result in shorter life cycle and rapid population expansion (Singh and Parihar 1988) which might affect generation time. Previously, it was thought that moisture contents of the manure have direct relationship with larval and pupal durations (Hogsette 1996). The current study revealed that moisture by itself is not responsible for the reduction of the duration of immature stages as buffalo and cow manures were the highest in their

Table 2 Biotic potential and intrinsic rate of natural increase on different livestock manures

Manure	Net reproductive rate (R_o per generation)	Intrinsic rate of natural increase (r_m per generation)	Biotic potential
Poultry	163.22	0.55	0.29
Nursing calf	140.59	0.49	0.26
Dog	124.50	0.46	0.25
Cow	81.93	0.40	0.23
Horse	54.33	0.30	0.18
Buffalo	82.80	0.39	0.23
Sheep	63.10	0.33	0.20
Goat	61.98	0.34	0.21

water contents, but the development was slower on these hosts. These results are also in accord with the report (Patricia and Claudio 2008) that moisture alone is not responsible for rapid development; rather nutrient composition of the manure is important. The slow development of immature stages in the treatments based on cow, horse, buffalo, sheep, and goat manures could be linked with the nutritive quality of their excrement, with lower nitrogen content owing to their diet with higher carbon and fiber contents (Bary et al. 2004). Moreover, C:N ratio is usually lower in chicken manure compared to the cow and horse manures (Moon et al. 2001). Lower C:N ratio increases the quality of the manure with enhanced microbial activity, the factors essential for the development of immature stages of *M. domestica,* since the larvae feed more on the microorganisms that decompose organic material than on the same substrate (Ferrar 1987).

In the present study, the pupal weight of flies had a significant association with fecundity. On poultry, nursing calf, and dog manures, pupae were heavier, and maximum number of eggs per female was laid. The relationship between pupal weight and fecundity was also observed in other insects like *Spodoptera exigua* (Greenberg et al. 2001) and in *Aedes* mosquitoes (Armbruster and Hutchinson 2002) where both realized and potential fecundity were significantly associated with pupal weight of the insect. Besides differences in development period and pupal body weight, there was a marked variation in percentage survival and adults' eclosion on different types of manures. Larvae reared on horse, cow, sheep, and goat dung had relatively reduced eclosion rate compared with other host manures tested, followed by high level of prepupal mortality. Higher survival rate on poultry, calf, and dog manures might be due to low levels of early mortality which could be attributed to the suitability of these manures. The mortality of immature stages of an insect population, however, is an important factor in estimating adult populations (Lam et al. 2009).

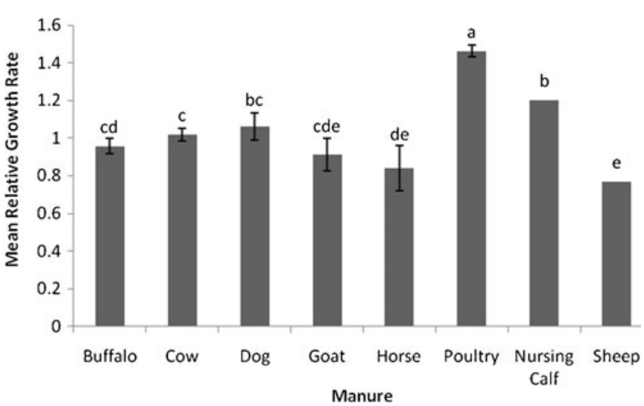

Fig. 1 Mean relative growth rate of *M. domestica* on different livestock manures. Bars with similar letters are not significantly different ($P>0.05$)

Females emerged from the larvae reared on poultry and calf manures laid higher number of eggs compared to the other hosts. The suitability of livestock manures as a larval resource depends on many factors that could modify the oviposition behavior of insects inhabiting such type of resource. Females prefer manures for oviposition in which their offspring could develop best (Lam et al. 2009). A variety of semiochemicals is involved in attracting female flies to oviposit (Cosse and Baker 1996). In addition, moderate level of moisture is also essential since the development, survival, and adult size are adversely affected by very high (Fatchurochim et al. 1989) or very low (Mullens et al. 2002) moisture levels. The variations in fecundity on different manures might reflect chemical cues that mediated manure selection in *M. domestica*. However, further studies should explore the role of semiochemicals of tested manures in attracting flies for oviposition.

The intrinsic rate of natural increase provides estimate of the growth potential of insect populations (Rabinovich 1972), which provide considerable insight aside from individual life history parameters. A close association between studied life history parameters on a specific host manure and intrinsic rate of natural increase was observed, which could reflect the potential of manures to support *M. domestica* populations. The net reproductive rate (R_o) is not, however, the core component to assess the potential of population growth since the intrinsic rate of natural increase is dependent on fecundity, percentage of eggs hatched, growth, and adults' eclosion (Saeed et al. 2010). Therefore, variations in any of the above life history traits could affect the rate of *M. domestica* population increase.

The longer developmental time of *M. domestica* on horse, sheep, and goat manures may provide an opportunity for the use of biocontrol agents against immature stages. Although, *M. domestica* feed on a variety of food materials, some hosts are preferred over the others owing to the nutritional factors (Malik et al. 2007). The present study shows that poultry, nursing calf, and dog manures are preferred hosts as developmental time was shortest on these hosts. This difference might be due to the fact of diets (Patricia and Claudio 2008) on which poultry birds, calves, and dogs were reared which contained protein as the major portion of their diets compared to the manure of other animals whose diet was based on crop residues, fodders, and grasses. However, further studies are needed to explore biochemical reasons for such differences.

The knowledge of differences in manures of different animals at farm level could have practical applications for the management of *M. domestica*. The results presented here could be useful to design cultural management of farm animal waste including moisture management, sanitation, and manure removal. Livestock manures including poultry, calf, and dog serve as important reservoirs for *M. domestica* populations that ultimately move and infect farm animals and human beings nearby. The present study provides information on the fitness of *M. domestica* in different livestock manures, with special emphasis on intrinsic rate of natural increase and biotic potential under the same environmental conditions. The successful management of *M. domestica* in livestock facilities will help to protect animals; however, in order to implement such strategy, a thorough knowledge of *M. domestica* ecology in diverse environmental conditions is needed.

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