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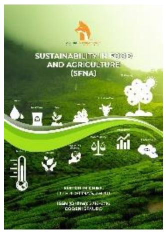

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RESEARCH ARTICLE

POTENTIAL USE OF ANIMAL MANURES IN MANAGING *PHYTOPHTHORA* WILT OF CHILLI CAUSED BY *PHYTOPHTHORA CAPSICI*

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ABSTRACT

Phytophthora wilt of chilli, caused by *Phytophthora capsici,* is a major concern for many growers because an effective management method has not been identified yet. In agriculture, animal manures have primarily been focussed on the supply of nutrients to the crops but their use for suppression of soil borne diseases is not well investigated and understood. In this study, we examined the efficacy of five different animal manures (poultry, cattle, goat, pig and sheep) at four levels (1, 5, 10 and 20% volume/volume) added to potting mix for management of *Phytophthora* wilt of chilli. The preliminary study revealed that the quantity of 5 g per pot (500 mL) of *P. capsici*-colonised millet-seed inoculum was effective for the development of *Phytophthora* wilt in chilli seedlings grown in coir-based potting media. The main greenhouse experiments were conducted in randomised complete design with five replications. The results showed that all types of manures were effective in increasing the survival rate of chilli by reducing the incidence of *Phytophthora* wilt. In the first planting all manures caused at least two-fold increase in plant survival compared to the inoculated control. The chilli plant survival was much higher in the second planting when seedlings were planted after six week of incorporation of manures and seven weeks after inoculation of potting mix. Among manures, the highest plant survival percentage at the final assessment was found in pots amended with 20% v/v poultry manure in both the first (66%) and the second (86%) plantings. For sustainable and effective management of *Phytophthora* wilt of chilli, this study recommends application of poultry manure to growing media two months before planting of chilli seedlings.

KEYWORDS

Chili, Manure, Plant survival, Potting mix, Phytophthora wilt

1. INTRODUCTION

Phytophthora wilt of chilli, caused by a soil-borne oomycete plant pathogen, *Phytophthora capsici* Leonian, is a devastating disease on field grown chilli worldwide that causes significant economic loss. Globally, *P. capsici* causes losses of more than $100 million annually (Barchenger et al., 2018). It is a fast spreading, aggressive disease, capable of causing complete crop failure in rainy weather. The symptoms of *Phytophthora* wilt of chilli can vary depending on the part of the plant infected and the stage of crop development. *P. capsici* can infect chilli plants at any growth stage. Infected seedlings show typical damping-off symptoms. Infection of older plants usually begins at the soil line, and wilting of infected plants first appears in low-lying areas of a field where water commonly accumulates after irrigation or rain.

The typical symptoms on mature plants may include crown rot, stem lesions, foliar blight, and fruit rot (Granke et al., 2012). The pathogen is spread mainly through irrigation water and runoff from rain (Cafe-Filho et al., 1995). Management of *Phytophthora* wilt of chilli in North America is challenging due to the pathogen's broad host range, production of long-lived dormant sexual spores (oospores), presence of extensive genotypic diversity, and occurrence of explosive asexual disease cycle in favourable weather conditions (Lamour et al., 2012). The implementation of an integrated management strategy for *P. capsici* remains difficult because resistant cultivars are not available and crop rotation and other cultural practices have little effect (Hausbeck and Lamour, 2004).

Chemical control has been the most effective method in managing *Phytophthora* wilt of chilli (Lamour and Hausbeck, 2000). Currently, two widely used systemic fungicides for control of *Phytophthora* disease in chilli are metalaxyl and phosphonate (Matheron and Porchas, 2000; Sanogo and Ji, 2012). These fungicides provide systemic protection against oomycete pathogens (Fenn and Coffey, 1987). However, continuous use of the chemical fungicides is not only harmful to the environment and consumers' health but it can also lead to the development of resistant strains of *P. capsici*. Resistance of *P. capsici* isolates to mefenoxam has been reported in many states of the USA, as well as in Europe (Parra and Ristaino, 2001; Hausbeck and Lamour, 2004; Silvar et al., 2006). Additionally, a great proportion of *P. capsici* isolates in the USA were resistant to another newer fungicide, cyazofamid, based on mycelial growth or sporangial production (Jackson et al., 2012). Although the development of phosphonate resistance in *Phytophthora* species is unlikely, phosphonate tolerance has been reported in the laboratory (Dolan and Coffey, 1988).

There is a renewed interest in the use of organic soil amendments for the control of soil-borne plant diseases including *Phytophthora*. Composts and manures have the potential to significantly reduce *Phytophthora* root and

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crown rots of chilli (Hoitink et al., 1991; Nemec and Lee, 1992). Physical, chemical, and biological mechanisms of organic amendments for disease suppression have been identified (Hoitink and Fahy, 1986). Manures have been found to control fungal diseases caused by *Fusarium* spp. and *Sclerotinia sclerotiorum* (Asirifi et al., 1994; Wicks et al., 1978; Osunlaja, 1990). Similarly, poultry manure has been shown to be highly effective in increasing seedling survival of lupin (*Lupinus albus*) when challenged with *P. cinnamomi* (Aryantha et al., 2000). In spite of these findings on the beneficial impacts of organic amendments on the control of plant disease, use of animal manures has primarily been focussed on the nutritional benefits derived by crops (Conn and Lazarovits, 1999). Small-holder farmers around the world have access to quantities of animal manures but they are either ignorant or hesitant to use them for disease control purpose. The goals of this study was to evaluate the potential of un-composted aged manures to reduce the incidence of *Phytophthora* wilt of chilli caused by *P. capsici* on disease-sensitive chilli seedlings under growth room conditions.

2. Materials and Methods

2.1 Experimental site and plant growth environment

Two separate pot trials were conducted in a temperature-controlled glasshouse at The University of Sydney to explore the suppressive properties of manures on *Phytophthora* wilt in chilli plants. The growing conditions in both the greenhouse experiments consisted of natural lighting but day temperature was maintained at 27^{o}C for 18 h and night temperature at 22^{o}C for 6 h. Free-draining plastic pots of 500 mL capacity were used in all experiments and each experimental unit consisted of 10 plants per pot.

2.2 Plant preparation for bioassay

Seeds of a susceptible chilli cultivar, 'Sha Ema', were imported from Bhutan for both the experiments. The chilli seeds were sterilised following the protocol described for tobacco seeds (Guest 1986). Briefly, the seeds were surface sterilised by immersing them for 1 min in 15 mL of 10% household bleach solution (125 g/L available chlorine) followed by dipping in 10 mL of 75% ethanol for 1 min and thorough rinsing with 200 mL of sterile distilled water. The seeds were sown in sterilised propagating sand (Bunnings, Vic., Australia) in plastic nursery trays in the glasshouse at 22^{o}C for germination. The trays were watered daily to keep the medium moist. After emergence, the seedlings were fed weekly by drenching with 400 mL of Aquasol® (Yates, Padstow, NSW, Australia) solution per tray containing 1 g/L of Aquasol®. When the seedlings were two weeks old after emergence, they were uprooted, keeping the root system intact, and planted into the 500 mL plastic pots in two different pot experiments described below.

2.3 *P. capsici* isolate and inoculum preparation

Cultures of *P. capsici* isolate W112 originally isolated from symptomatic chilli plants in Vietnam and virulent on chilli were obtained from the Royal Botanic Gardens, Sydney, on agar plugs. To revive the virulence of pathogen after retrieving from long-term storage, the isolate was artificially inoculated onto and re-isolated from capsicum fruits. *P. capsici*-colonised millet seed inoculum was used in both the experiments. The method described by Quesada-Ocampo et. (2009) was used to prepare millet seed inoculum but without adding asparagine. Seeds of white French millet (*Panicum miliaceum* L.) were procured from the market (Freshco Foods, Silverwater, NSW, Australia). Millet seed (100 g) was transferred to a netted filter, thoroughly washed in running water for 10 min, drained water and placed in a 500 mL Erlenmeyer flask.

The seeds were soaked in 72 mL of deionised water, the neck of the flask was plugged with cotton wool and capped with aluminium foil. The flask was then autoclaved at 121^{o}C and 100 kPa for 20 min on two consecutive days. The medium was cooled to room temperature and aseptically inoculated in the laminar flow hood with four 7-mm-diameter agar plugs from the edge of an actively growing *P. capsici* culture on 20% CA medium (Stelfox and Herbut, 1979). The flask was shaken on alternate days to homogenise the mixture. The inoculated millet seeds were incubated at room temperature 21°C (± 2°C) under constant fluorescent light for 4 weeks. For control pots, the sterile millet seeds were similarly prepared with agar plugs without any mycelia of *P. capsici* or other pathogens. A separate batch of millet seed inoculum was prepared for each experiment.

2.4 Experiment 1: Evaluation of potting mixes and doses of inoculum of *P. capsici*

The objectives of this experiment were to: (1) determine the optimum quantity of *P. capsici*- colonised millet-seed inoculum effective for the development of *Phytophthora* wilt of chilli on young seedlings, and (2) select a potting mix that was conducive to growth of *P. capsici* and without any suppressive effect. Coir, prepared from coconut (*Cocos nucifera*), is becoming a popular potting medium in nursery production due its desirable qualities like high water holding capacity, excellent drainage, and the fact that it is a renewable resource. However, it has been reported that that coir can suppress some soil borne plant pathogens including *Phytophthora capsici* (Hyder et al., 2009). In this study, two potting mixes prepared from either sphagnum peat or coconut coir were compared for their conduciveness to *Phytophthora* wilt of chilli on young seedlings.

The method described by Kim et al. (1997) for the preparation of a sphagnum peat mix potting medium was used with some modifications. Briefly, peat moss (Bunnings, Oakleigh South, Vic., Australia) was mixed with coarse horticultural grade perlite (Bunnings, Oakleigh South, Vic., Australia) at a volumetric ratio of 7:3. The initial pH of the mix was 4.3 and it was amended with 5.4 g of dolomite and 3.6 g of calcium carbonate per litre of mix to raise the final pH to 7.0. A coconut coir-based mix was prepared by mixing premium grade coir (Coir Power, Bunnings, Oakleigh South, Vic., Australia) and washed river sand (Paver Sand, Bunnings, Oakleigh South, Vic., Australia) at a volumetric ratio of 1:1. The pH of the coir mix was 6.9 when measured using the 1:5 water dilution method in a glass electrode potentiometer. Plastic pots were fully filled with either the peat or coir-based transplanting mixes and 10 chilli seedlings were planted in each pot.

The amount of millet seed inoculum investigated were: 0.0 (control), 0.5, 1.0, 5.0, or 10.0 g/pot. Plants were inoculated immediately after transplanting of seedling by carefully placing the required quantity of millet seed infested with *P. capsici* at about 2 cm deep directly into the media at four different locations per pot. For inoculation, two steel tablespoons were used: one for lift the potting mix from the pot and replacing the mix to the pot, another for inserting the inoculum into the potting media. The control pots were similarly mock-inoculated with sterile millet seeds. The treatment pots were arranged in a completely randomised design with three replications.

Irrigation was provided with overhead sprinklers for 7 min on a 24 h cycle. In addition to sprinkler irrigation, a series of wet and dry cycles were created to promote infection by *P. capsici*. This was achieved by placing a plastic saucer at the bottom of each pot that was flooded continuously for three days and inverted for the next four days. The chilli plants were provided with supplementary nutrient weekly by drenching with 100 mL per pot of an aqueous solution of 1 g/L Aquasol® (Yates, Padstow, NSW, Australia). The assessment of disease incidence and plant survival was initiated one week after planting as described below in the sub-section 2.6.

2.5 Experiment 2: Evaluation of manures for their ability to suppress *Phytophthora* wilt of chilli caused by *P. capsici*

The objective of this study was to evaluate the different quantities of un-composted manures for reducing the incidence of wilt caused by *P. capsici* on inoculated chilli seedlings. Unpasteurised, commercial poultry, cattle, and sheep manures were procured from the market (Bunnings, Vic., Australia), while aged goat and swine manures were collected from private farms in Camden, NSW, Australia as they were not available commercially in the market. The raw, unprocessed swine and goat manures were ground to an identical texture to other commercial manures. The coir–sand potting mix was infested with millet seed inoculum at a calculated rate of 5 g per plastic pot (500 mL capacity) and incubated for 1 week in a 12-L plastic bucket, keeping the bucket moist. One week after incubation of potting mix, manures were then well mixed with potting mix separately at the rates of: 0 (control), 1, 5, 10 or 20% volume by volume (v/v).

Each plant pot was filled with manure-amended transplanting mix and 10 chilli seedlings were planted one week after addition of manure. The inoculated control pots had *P. capsici* inoculum (5 g/pot) but no manure, and the non-inoculated control pots had manures (10% v/v) but no inoculum of *P. capsici*. The pots (experimental units) were arranged in a randomised complete block (RCB) design and each pot was replicated five times. The fertilizer and irrigation were managed as described in the sub-section 2.4 (Experiment 1). The incidence of disease occurrence and plant survival in different manure types were then assessed for three weeks starting from one week after planting of seedlings. The method of assessment of disease incidence and plant survival is described in sub-section 2.6 below.

Wilted seedlings including roots were harvested weekly for determination of the total fresh and dry weights. The harvested plants were washed in running tap water to remove potting mixes from the roots and excess moisture was removed by wiping with tissue paper. All seedlings, including the healthy ones, were harvested at the end of the third week after planting and their total fresh and dry weights were determined. The total dry weight was determined by drying the plants in an oven at 65°C to a constant weight. After harvesting the plants, the pots were left undisturbed (to simulate fallow condition) for an additional two weeks, with light watering on alternate days just to keep the pots moist. The pots were then replanted with 10 freshly grown chilli seedlings that were of the same age as in the first planting. No new inoculation was made to the pots and disease incidence was again assessed for three weeks after planting of seedlings. The total fresh and dry weights of harvested plants were determined as described in the first planting.

2.6 Assessment of plant survival and disease incidence

Recording of plant survival and assessment of disease incidence in all the experiments was initiated one week after planting and was continued weekly until the third week. Plants were considered as “healthy and surviving” if they were not wilted or no crown rot lesions were observed. Data on plant survival were collected by counting the number of surviving plants, and the percentage plant survival was determined as [(number of healthy plants/total number of plants per pot) × 100] (Kim et al., 1997). Data presented are the mean of all replicates of each treatment. The identity of the causative pathogen as *P. capsici* was confirmed by plating infected root tissues of all symptomatic plants on a *Phytophthora*-selective medium (PARPH; pimaricin, 5 µg/mL; ampicillin, 250 µg/mL; rifampicin, 10 µg/mL; pentachloronitrobenzene, PCNB, 100 µg/mL; and hymexazol, 50 mg/mL) followed by morphological verification with light microscopy.

2.7 Statistical analysis

Statistical analysis was performed using Statistical Analysis System (SAS Institute, Cary, NC, USA). Data on percent plant survival, and total fresh and dry plant biomass were statistically analysed by one-way analysis of variance (ANOVA). The statistics performed compared the level of disease incidence at the indicated date. Treatment means were compared with Fisher's protected least significant differences (LSD) test (p = 0.05). Standard errors (SE) of means were also computed.

3. Results and Discussion

3.1 Experiment 1: Evaluation of potting mixes and doses of inoculum of *P. capsici*

Symptoms of *Phytophthora* wilt of chilli were first observed on the seedlings during the first week after inoculation. The percentages of plant survival inoculated with different quantities of inoculum seven days after inoculation differed significantly irrespective of the type of transplanting mix used (Table 1). Generally, more seedling deaths were observed at higher inoculum levels in both the potting mixes (Figure 1). However, no statistically significant difference was recorded in plant survival between transplanting mixes prepared with coir and peat, and between inoculum levels of 5 and 10 g per pot. Plant survival in pots inoculated with 5 and 10 g per pot of millet seed inoculum varied from 31 to 38% at three weeks post inoculation (Table 1). Based on these results, the transplanting mix prepared with coconut coir and river sand (1:1 ratio v/v) and a millet seed inoculum dose of 5 g per pot were chosen for the main experiments (Experiment 2), as this combination caused enough disease symptoms in chilli seedlings for a reliable evaluation of plant survival. *P. capsici* was recovered from all seedlings showing disease symptoms on re-isolation on PARPH media (data not shown).

Table 1: Survival of chilli seedlings (%) in coir or peat-based potting mixes inoculated with different quantities of millet seed inoculum of P. capsici on the day of planting

Treatment	Plant survival (%)		
	Week 1	Week 2	Week 3
Coir–sand + 0.0 g Pc	100^{a}	100^{a}	100^{a}
Coir–sand + 0.5 g Pc	100^{a}	93^{ab}	60^{b}
Coir–sand + 1.0 g Pc	97^{ab}	93^{ab}	53^{c}
Coir–sand + 5.0 g Pc	93^{ab}	77^{c}	38^{d}
Coir–sand + 10.0 g Pc	90^{b}	68^{c}	33^{d}
Peat–perlite + 0.0 g Pc	100^{a}	100^{a}	100^{a}
Peat–perlite + 0.5 g Pc	100^{a}	90^{b}	63^{b}
Peat–perlite + 1.0 g Pc	97^{ab}	87^{b}	53^{c}
Peat–perlite + 5.0 g Pc	97^{ab}	74^{c}	36^{d}
Peat–perlite + 10.0 g Pc	90^{b}	73^{c}	31^{d}
$P > F$	0.0147	0.0001	0.0001
CV (%)	3.9	5.3	9.7

Pc = *Phytophthora capsici*; CV = Coefficient of variance. Means in columns with common letter(s) do not differ significantly at $P \leq 0.05$

Figure 1: Survival of chilli seedlings at three weeks post inoculation of *P. capsici*-colonised millet seed inoculum per pot in transplanting mixes prepared with (a) coconut coir and sand (C+S), and (b) sphagnum moss peat and perlite (P+P)

3.2 Experiment 2: Evaluation of manures for their ability to suppress *Phytophthora* wilt of chilli caused by *P. capsici*

In this study, all four levels (1%, 5%, 10%, and 20% v/v) of poultry, cattle, goat, swine, or sheep manure delayed chilli seedling death due to *Phytophthora* wilt caused by *P. capsici* under greenhouse conditions (Figures 3–5). This suppression by manure amendments persisted when a second planting of fresh seedlings were done in the same pots. All manures caused a two-fold increase in plant survival compared to the inoculated control at the final evaluation at three weeks post planting. Generally, plant survival increased with an increase in the volume of manure added to the transplanting mix irrespective of the manure type in both the first and the second plantings. In all manure types, the highest plant survival percentage was found in pots amended with 20% v/v manure. Among manures used in the bioassay, the highest plant survival percentage at the final assessment (three weeks post planting) was found in pots amended with 20% v/v poultry manure in both the first (66%) and the second (86%) plantings. The corresponding plant survival percentages in cattle, goat, swine, and sheep manures were 54, 56, 48 and 52%, respectively in the first planting, and 76, 72, 68 and 70%, respectively in the second planting.

Figure 2: Survival of chilli seedlings at three weeks post inoculation, (a) the first planting in poultry manure, and (b) infected roots of inoculated seedlings (left) and healthy roots of non-inoculated 3-week-old seedlings (right)

In all treatments including the inoculated control, seedling survival was much higher in the second planting (i.e. planted seven weeks after inoculation) than in the first planting (Figures 3 – 5). The final seedling survival percentages in the second planting in poultry, cattle, goat, swine, and sheep manure-amended pots increased by 30–52%, 41–64%, 29–32%, 33–45%, and 35–57%, respectively compared to the first planting.

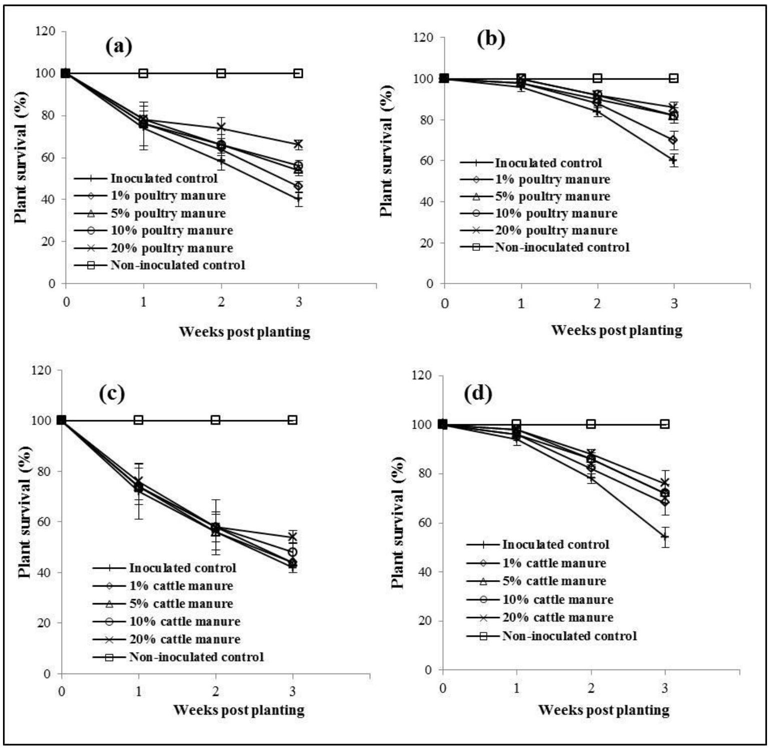

Figure 3: Survival of chilli seedlings on coir–sand potting mixes amended with varying proportions of (a and b) chicken, and (c and d) cattle manures infested with 5 g of *Phytophthora capsici*-colonised millet seed inoculum, in (a and c) first, and (b and d) second plantings (mean of five replicates). Error bars represent standard errors of the mean. The inoculated controls included *P. capsici* but no manure, and the non-inoculated controls included manure but no *P. capsici*

3.3 Total fresh and dry weight of chilli plants

Both total fresh and dry weights of chilli plants were increased with greater volumes of manure added to the potting mix. In all manure-treated pots, plants with the highest total fresh and dry weights were recorded in pots amended with 20% manure (v/v), and the values declined with decreasing percentages of manure amended into the potting mix (Figures 6-8). Generally, the total plant biomass was strongly correlated with plant survival in the first planting, but this trend was not observed in the second planting. In the first planting, 20% poultry manure had the highest seedling survival percentage (66%) and also produced plants with the highest fresh (485 mg/plant) and dry (74 mg/plant) weights. However, in the second planting, although 20% poultry manure had the highest seedling survival (86%), the highest fresh weight was recorded in 20% cattle manure (939 mg/plant), and the highest dry weight was recorded for chilli plants grown in 20% sheep manure (197 mg/plant).

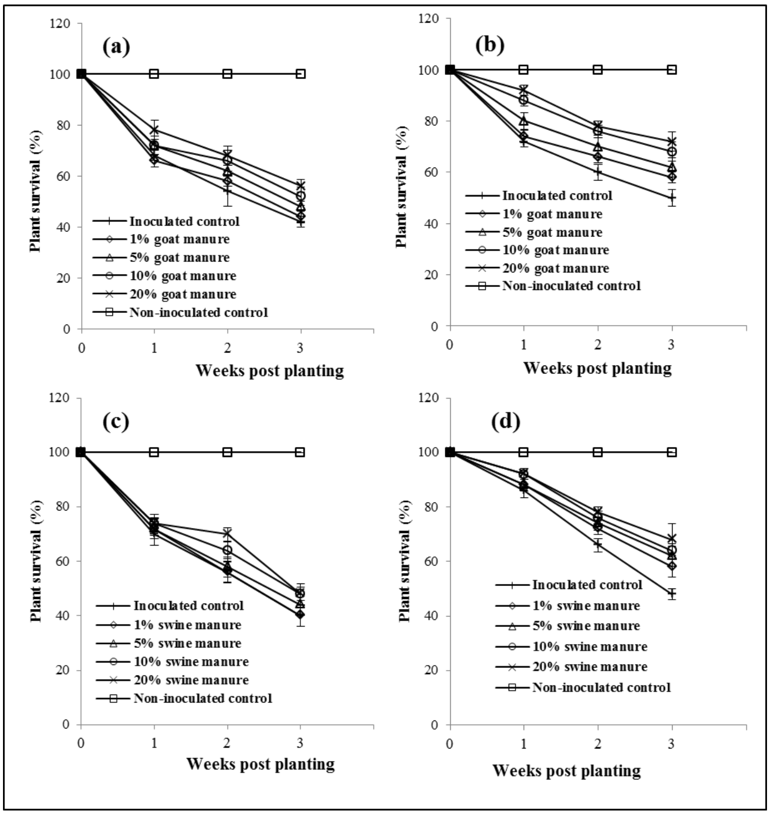

Figure 4: Survival of chilli seedlings on coir–sand potting mixes amended with varying proportions of (a and b) goat, and (c and d) swine manures infested with 5 g of *Phytophthora capsici*-colonised millet seed inoculum in (a and c) first, and (b and d) second plantings (mean of five replicates). Error bars represent standard errors of the mean. The inoculated controls included *P. capsici* but no manure, and non-inoculated controls included manure but no *P. capsici*

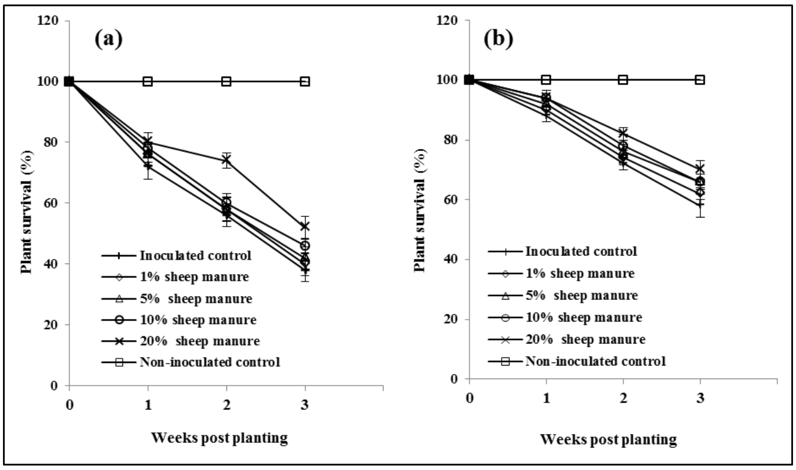

Figure 5: Survival of chilli seedlings on coir–sand potting mixes amended with varying proportions of sheep manure infested with 5 g of *Phytophthora capsici*-colonised millet seed inoculum in (a) first, and (b) second plantings (mean of five replicates). Error bars represent standard errors of the mean

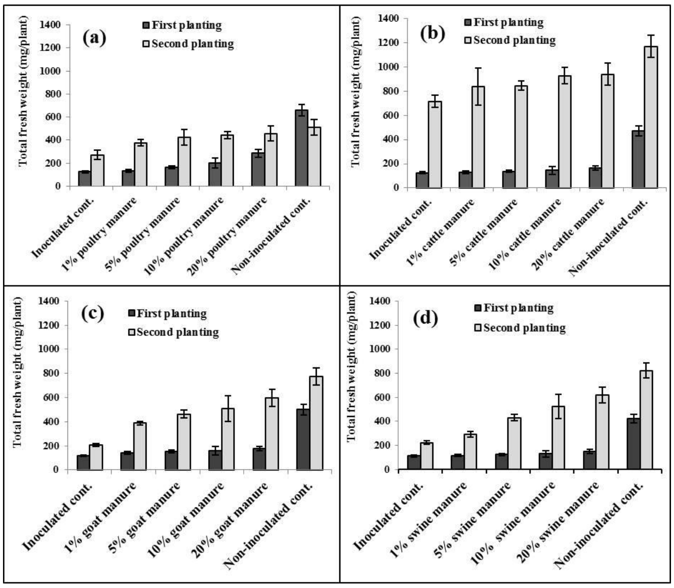

Figure 6: Effects of (a) poultry, (b) cattle, (c) goat, and (d) swine manures on the total plant fresh weight of chilli seedlings grown in a *Phytophthora capsici*-infested coconut coir-based potting mix. Error bars represent the standard errors of the mean

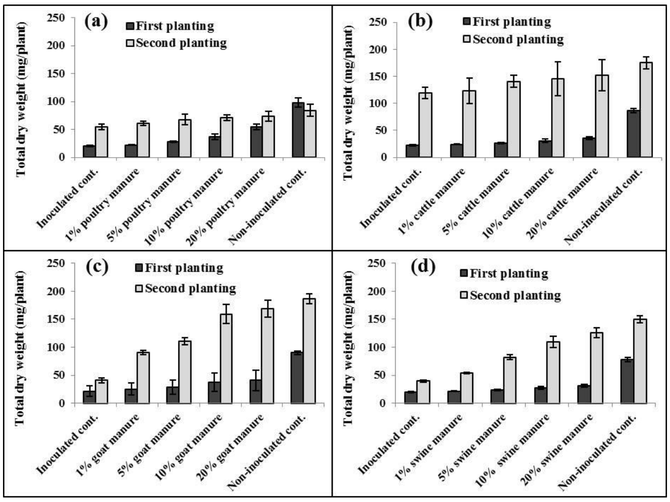

Figure 7: Effects of (a) poultry, (b) cattle, (c) goat, and (d) swine manures on the total plant dry weight of chilli seedlings grown in a *Phytophthora capsici*-infested coconut coir-based potting mix. Error bars represent the standard errors of the mean

4. Discussion

We evaluated five animal manures (poultry, cattle, goat, swine, and sheep) in separate pot cultures for the control of *Phytophthora* wilt of chilli on seedlings inoculated with *P. capsici*. The results of this study showed that applications of all types of manures were more effective in reducing the incidence of *Phytophthora* wilt of chilli in the second planting. In the second planting, the survival of seedlings replanted into pots that were kept fallow for 2 weeks after the harvest of the first planting (i.e. planted 7 weeks after soil inoculation) were compared with that of the first planting when seedlings had been planted into pots freshly inoculated with *P. capsici* inoculum. The plant survival percentages in the second planting were greater than for those in the first planting. Further, pots amended with 20% (v/v) chicken manure increased seedling survival (86%) more than other treatments in the second planting. Thus, a single application of chicken manure can cause a dramatic decrease in plant death from *Phytophthora* wilt of chilli. The same rate of cattle and goat manures were also effective in reducing plant death from *Phytophthora* wilt of chilli in the second planting.

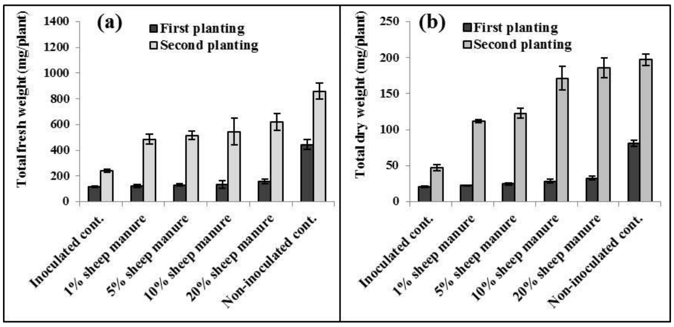

Figure 8: Effects of sheep manures on the total plant (a) fresh, and (b) dry weights of chilli seedlings grown in a *Phytophthora capsici*-infested coconut coir-based potting mix. Error bars represent the standard errors of the mean

The higher plant survival following manure amendments in the second planting might have resulted either from the lower inoculum level in the potting mix at the time of second planting, or from the increased suppressive capacity of manures at the later period. In our experiments, the wilted plants were removed (uprooted) from the inoculated pots on weekly intervals for determination of plant biomass. This process of removal of infected plants from the pots might have acted as a "trap crop" and helped in reducing the inoculum level of the pathogen in the potting mix. However, we did not quantify the inoculum level of *P. capsici* in the pots at the time of second planting to test this hypothesis. The assumption of increased suppressive capacity of manures at the later period was supported by increased microbial activity in cattle, goat, and sheep manures in the second planting compared to the first planting (data not shown). The better plant survival in the second planting might be due to the combination of the both effects. Nevertheless, our data demonstrated the importance of rogueing of infected plants from the fields for reducing disease incidence in the following cropping season.

Our studies with animal manures support previous research findings. A previous research reported that composted poultry manure gave better control of root rot of lupin seedlings caused by P. cinnamomi than cow, horse, or sheep manures in a greenhouse experiment (Aryantha et al., 2000). Similarly, the repeated bio-disinfection with a semi-composted organic amendment consisting of a mixture of horse and chicken manures in an equal proportion had the lowest disease incidence of *Phytophthora* root and crown rot in sweet pepper in Spain (Núñez-Zofío et al., 2010). Further, in a field experiment conducted in Canada, chicken and swine manures reduced the incidence of *verticillium* wilt and potato scab to nearly zero (Conn and Lazarovits, 1999).

Organic amendments including manures, suppress soil-borne diseases by physical, chemical, and biological mechanisms (Hoitink and Fahy, 1986). Application of poultry manure increases soil pH and temperature, and detectable quantities of ammonia and nitrite accumulate in the chicken manure-amended soil (Tsao and Oster, 1981; Schilke-Gartley and Sims, 1993). Soil temperature above 50°C is harmful to soil-borne plant pathogens (Katan et al., 1976; Lodha et al., 1997). Ammonia is highly toxic to living organisms, and is reported to have been involved in killing *Phytophthora cinnamomi* Rands and *Fusarium oxysporum* Schlecht (Warren, 1962; Zakaria et al., 1980).

The following five biological mechanisms of disease control of soil-borne plant pathogens by organic amendments have been postulated by Hoitink and Boehm (1999): (i) parasitism against pathogens by beneficial micro-organisms, (ii) antibiotic production by beneficial micro-organisms, (iii) competition for nutrients by beneficial micro-organisms, (iv) inducing systemic resistance in plants by micro-organisms, and (v) supplying plant nutrition and improving vigour, leading to enhanced disease resistance. Application of animal manures in vegetables production not only controls soil-borne but also reduces the use of pesticides and fertilizers and restores the eco-logical environment. Unlike chemical fungicides, organic soil amendments provide major plant nutrients, increase organic matter content and improve other physico-chemical properties of the soil, all of which collectively contribute to increase in plant growth and crop yields.

5. Conclusion

Phytophthora wilt of chilli is a serious disease worldwide, and its effective management can be achieved only through implementation of integrated disease management strategies with chemical control as the last option. The integrated management of *Phytophthora* wilt of chilli must use *Phytophthora* suppressive organic soil amendments like poultry and cattle manures, the efficacy of which is reported in this study. Data from our greenhouse study showed that applications of all types of manures (poultry, cattle, goat, swine, and sheep manures) were effective in reducing the incidence of *Phytophthora* wilt and increasing the survival rate of chilli. All manures caused a two-fold increase in plant survival compared to the inoculated control at the final evaluation three weeks post planting.

The chilli plant survival was much higher in the second planting when seedlings were planted after six week of incorporation of manures and seven weeks after inoculation of potting mix. Among manures used in the bioassay, the highest plant survival percentage at the final assessment was found in pots amended with 20% v/v poultry manure in both the first (66%) and the second (86%) plantings. Thus, this study recommends the soil application of poultry manure 1.5 - 2 months before planting of chilli for effective management of *Phytophthora* wilt caused by *Phytophthora capsici*. This study demonstrated the efficacy of manures as a non-chemical method effective in in management of *Phytophthora* wilt of chilli. However, further study is required to analyse the density of the pathogen in container media amended with different types and quantities of manures.

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