EFFECT OF VERMICOMPOST ON WHEAT AT DIFFERENT ARSENIC LEVELS

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CERTIFICATE

*This is to certify that thesis entitled, "**EFFECT OF VERMICOMPOST ON WHEAT AT DIFFERENT ARSENIC LEVELS**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (MS) in AGRONOMY**, embodies the result of a piece of bona-fide research work carried out by **MT. JESMIN AKTAR LABONY**, Registration no.* **14-05811** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Date:
Place: Dhaka, Bangladesh

Prof. Dr. Md. Shahidul Islam
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Dedicated

to

My Beloved Parents

And

Respected Research Supervisor

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ABSTRACT

An experiment was conducted at the net house of the Department of Agronomy, Sher-e-Bangla Agricultural University during the period from November, 2019 to March, 2020 to investigate the effect of vermicompost on wheat at different arsenic level. The experiment comprised of two factors viz. Factor A: Arsenic concentrations (3), i. A_0: control (No As), ii. A_1: 25 mg As kg^{-1} soil and iii. A_2: 50 mg As kg^{-1} soil; Factor B: Vermicompost doses (3), i. V_0: 0 t ha^{-1}, ii. V_1: 2.50 t ha^{-1} and iii. V_2: 5.00 t ha^{-1}. This experiment was laid out in a Completely Random Design (CRD) with six (6) replications. Data were collected on different aspects of growth, yield attributes and yield of wheat. The results revealed that treatment V_2 (5.00 t ha^{-1}) exhibited its superiority compare with other vermicompost treatments V_0 and V_1 in terms of seed yield. Treatment V_2 out-yielded over V_1 (2.50 t ha^{-1}) by 4.22% higher yield. Treatment V_2 also showed the highest weight of 100-grains (2.69 g), maximum length of wheat spike (6.979 cm), highest straw yield (25.39 g $plant^{-1}$), highest biological yield (47.47 g $plant^{-1}$) and the harvest index (46.62%) than other treatments in this experiment. On the other hand, the treatment V_0 (control or no vermicompost application) returned with 17.78% lower yield than treatment V_2 (5.00 t ha^{-1}) which was significantly the lowest compare with other treatments under study. Significant differences existed among different level of arsenic concentration with respect to yield and yield attributing parameters of wheat. A yield advantages of 3.12 g $plant^{-1}$ (14.67%) and 8.01 g m^{-2} (48.93%) over A_1 (25 mg As kg^{-1}soil) and A_2 (50 mg As kg^{-1}soil) treated plot, respectively was found which was possibly aided by higher plant height at harvest (64.52 cm), longer root length (8.53 cm), longer spike length of wheat (7.38 cm), higher number of grains $spike^{-1}$ (24.42), higher number of spikelets $plant^{-1}$ (13.40), heavier weight of 100-grain (2.82 g), straw yield (27.38 g $plant^{-1}$), biological yield (51.756 g $plant^{-1}$) and harvest index (47.17%) in the A_0 (control or no arsenic) treatment. On the other hand, between the two arsenic concentrations, A_1 treated pots performed better than A_2 treated pots regarding the growth, yield attributing and yield parameters. Among the interactions, V_1A_0 and V_2A_0 were superior in most of the growth and yield attributing parameters along with grain yield. Among the treatment combinations where arsenic was applied, V_1A_1 and V_2A_2 combinations showed better performance compared to other combinations. 2.50 t ha^{-1} of vermicompost application seems promising for combating 25 mg As kg^{-1} soil arsenic in wheat field.

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LIST OF ABBREVIATIONS

ABBREVIATION	**FULL WORD**
AEZ	Agro-Ecological Zone
%	Percentage
@	At the rate of
Agra.	Agricultural
Agric.	Agriculture
Agron.	Agronomy
Annu.	Annual
Appl.	Applied
BBS	Bangladesh Bureau of Statistics
Biol.	Biology
Chem.	Chemistry
cm	Centi-meter
CV (%)	Percent Coefficient of Variance
cv.	Cultivar (s)
DAS	Days After Sowing
Dev.	Development
Ecol.	Ecology
eds.	editors
Environ.	Environmental
et al.	et alia (and others)
etc.	et cetera (and other similar things)
Exptl.	Experimental
FAO	Food and Agriculture Organization
g	Gram (s)
Hortc.	Horticulture
i.e.	id est (that is)
J.	Journal
kg	Kilogram (s)
L.	Linnaeus

LIST OF ABBREVIATIONS

ABBREVIATION	**FULL WORD**
LSD	Least Significant Difference
M.S.	Master of Science
m^2	Meter squares
mg	Milligram
MoP	Muriate of Potash
Nutr.	Nutrition
Physiol.	Physiological
Progress.	Progressive
Res.	Research
SAU	Sher-e-Bangla Agricultural University
Sci.	Science
Soc.	Society
SRDI	Soil Resource Development Institute
t ha^{-1}	Ton per hectare
TDM	Total Dry Matter
TSP	Triple Super Phosphate
UNDP	United Nations Development Programme
var.	variety
Viz	*videlicet* (L.), Namely
Vm	Vermicompost
μMol	Micromole

CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the predominant cereal crops in the world under the Poaceae family and the main sources of carbohydrate and contains a considerable amount of protein, minerals and vitamins. It occupies global rank one in aspect of worldwide production and consumption. It is an important cereal crop of tropical and subtropical regions of the world. It is the third important cereal crop next to rice in Bangladesh (Al-Musa *et al.,* 2012). The area under wheat cultivation during 2018–2019 was about 3,30,348 hectares producing 10,16,811 metric tons of wheat with an average yield of 3.078 t ha^{-1} which is 1.66 % lower than that of last year (2017–18) (BBS, 2020).

On a worldwide scale, wheat contributes approximately 30% of total cereal production (Lobell and Gourdji, 2012). The wheat yield of Bangladesh is much lower comparing to other wheat producing countries in the world due to the fact of growing wheat under rain -fed condition (Bazzaz, 2013), which are very low in Bangladesh compared to the average yield of Ireland, Netherlands, Belgium and United Kingdom of Great Britain and Northern Ireland (9.38, 9.37, 9.33 and 8.93 t ha^{-1}, respectively) (FAO, 2019). Moreover, there can be a range of reasons for low yield of wheat including inadequate knowledge, lack of specifically adapted varieties, biotic stresses, abiotic stresses conditions such as drought, salinity, metal toxicity, extreme temperatures, low nutrient availability, and high ultraviolet radiation exposition also impose restrictions to growth and development of wheat plant.

There are numerous heavy metals, such as cadmium (Cd), lead (Pb), chromium (Cr), and arsenic (As) are increasing gradually into the agricultural land or soil. Arsenic (As) is a heavy metal, environmental toxicant and a ubiquitous trace element is found in ground water and agricultural land. Arsenic is taken up by plants and subsequently transformed in plant tissue and that is why it is therefore essential for estimating the risks posed to human and wildlife populations by Arsenic contaminated soils (Meharg and Hartley-Whitaker, 2002). It has been reported that Bangladesh is extremely high As contaminated regions where As concentration in water has been reported up to 3200 µg L^{-1} against the safe limit of 10 µg L^{-1} recommended by WHO (McCarty *et al*., 2011). Numerous sites are identified as As contaminant area in Bangladesh such as Jessore, Faridpur, Madaripur, Chapainouabgonj, Chandpur etc. Clinical manifestations of arsenic poisoning (arsenicosis) begin with various forms of skin diseases which often deteriorates and results in damages to internal organs and ultimately to cancer and death (Hossain *et al*., 2006). Arsenic causes skin lesions, cancer of lungs, bladder, disease of cardiovascular system, diabetes, reproductive failure etc. in human beings (Smith *et al*., 1992; Tseng *et al.*, 2003; Navas-Acien *et al.*, 2008; Hendryx, 2009).

In addition, the rate of arsenic contamination increasing day by day due to As contamination from ground water by excess use of pesticides, anthropogenic activities etc. Thus, the flora and fauna become vulnerable to arsenic contaminated environment. The major forms of arsenic are arsenate (AsV) and arsenite (AsIII). These forms are taken up by different mechanism and mobilized inside the plants. The causes of arsenic toxicity are mainly due to interference in ATP synthesis and alteration in protein structure and catalytic properties (Sinha *et al*., 2013).

Imbalanced fertilizer application is one of the major causes of low yield of wheat in Bangladesh (Sabrah *et al.*, 1995). Continuous use of large amounts of only N, P and K is expected to influence not only the availability of other nutrients to plants because of possible interaction between them but also the build-up of some of the nutrients creating imbalances in soils and plants leading to decreased fertilizer use efficiency (Nayyar and Chibba, 1992). It is essential to identify the status of the essential plant nutrients, how they decrease or increase yield and quality of crop and the way by which their available amounts can be maintained in forms and at levels that can give high crop production in the long-term use.

Obviously, it is very difficult to determine the exact reason what occurs. But it is clear that this occurs consistently under a particular soil, crop or seasonal condition, then it is a factor that must be considered in sound fertilizer recommendation (Tandon, 1992).

Compost produced by traditional processes is generally low in plant nutrient content and the process itself is also slow and time consuming. On the other hand, certain special type of earthworm (*Eisenia foitida*) has the capacity to convert the biodegradable organic waste into higher quality compost at comparatively faster rate (Bhattarai, 2003) than that of the traditional method. Such a compost usually known as "vermicompost" is rich in plant nutrients and contains higher number of microorganisms, which are responsible for decomposition process (Yami *et al*., 2003).

Vermicompost is important in sustainable agriculture (Simanaviciene *et al.*, 2001). Vermiculture can only be done on compostable or decomposable organic matter. It can also be an important agent of pedogenesis. Bevacqua and Mellano (2013) reported that vermicompost treated soils had lower pH and increased levels of organic matter, primary nutrients, and soluble salts. Edwards and Burrows (2010) reported that vermicompost, especially those from animal waste sources, usually contained more mineral elements than commercial plant growth media. According to Amo-Aghaee *et al*. (2003), this type of organic fertilizers is not only safe for environment but if it applied in higher dose, unused nitrogen remained in soil in the form of organic nitrogen and it will eventually return to the plant at the times of its need by process of mineralization. In terms of intangible returns vermicompost not only supplies essential elements to plant but also improves physiochemical and biological properties of soil, thus having promise to marginal and resource poor farmers and this may be a good asset for sustainable agriculture.

Considering the above facts, the present study was undertaken with the following objectives:

- To determine the influence of arsenic on growth and yield of wheat.
- To explain the effect of vermicompost on growth and yield of wheat.
- To examine the effects of vermicompost treatments on As induced oxidative stress.

CHAPTER II

REVIEW OF LITERATURE

In perspective of Bangladesh, arsenic (As) an abiotic stress is one of the serious problems in agricultural sector. Arsenic is a highly toxic metalloid and its contamination in soil and water has become an important environmental concern. As is taken up by plants and subsequently transformed in plant tissue is therefore essential for estimating the risks posed to human and wildlife populations by As contaminated soils (Meharg and Hartley-Whitaker, 2002). The scientists of Bangladesh are conducting different experiments to adopt different crops in the As contaminated soil; wheat is one of them. Very limited research works have been conducted to adapt wheat in the As stressed condition of Bangladesh. It is an attempt to find out the performance of wheat at different levels of Arsenic as well as to find out the possible mitigation with the use of different levels of vermicompost. To facilitate the research work, different literatures from home and abroad have been reviewed in this chapter under the following headings:

2.1 Effect of arsenic on wheat

Kamrozzaman *et al.* (2016) conducted an experiment at Farming System Research and Development Site, Hatgobindapur, Faridpur during 2012–13 to evaluate five wheat varieties against arsenic contaminated soils and determined accumulation of arsenic in grain and straw of wheat varieties. BARI Gom-21, BARI Gom-23, BARI Gom-24, BARI Gom-25 and BARI Gom-26 were used as treatment variables. The study area was contaminated with arsenic and the level of arsenic in groundwater greatly exceeded WHO permissible limit for drinking water (0.01 mg L^{-1}) and Food and Agricultural Organization permissible limit for irrigation water (0.10 mg L^{-1}). Amount of total soil arsenic was 28.60 mg kg^{-1} in initial soil and 28.87 mg kg^{-1} in post-harvest soil. Irrigation water arsenic level was 0.25 mg L^{-1} in post-harvest soil. Results revealed that, wheat varieties differed in their grain arsenic concentration (0.49–1.15 mg kg^{-1}). The arsenic translocation in wheat grains was usually the least and accumulation by different tissues followed the order root > stem > leaf > grain across the varieties. The variety BARI Gom-26 was found to accumulate least arsenic in grains followed by BARI Gom-25 and BARI Gom-24 the highest under same growing condition due to phytoextraction or phyto-morphological potential of the varieties. Maximum grain yield (4.36 t ha^{-1}) was obtained from BARI Gom-26 followed by BARI Gom-25 and the lowest yield (3.43 t ha^{-1}) was recorded from BARI Gom-23. The yield reduction order among the varieties were as follows: BARI Gom-26 > BARI Gom-25 > BARI Gom-24 > BARI Gom-21 > BARI Gom-23 but arsenic uptake in grain was found different such as BARI Gom-24 > BARI Gom-21 > BARI Gom-23 > BARI Gom-25 > BARI Gom-26. Therefore, BARI Gom-26 and BARI Gom-25 can successfully be grown for higher yield in arsenic contaminated soils and water of Faridpur.

Jahan (2016) conducted a pot experiment to examine the role of sodium nitroprusside (SNP) as NO donor on mitigation of As toxicity in wheat. In this experiment, the treatment consisted of four different As levels, *viz*. As_0 = without As (control), As_1 = 30 mg As·kg^{-1} soil, As_2 = 60 mg As kg^{-1} soil, As_3 = 90 mg As kg^{-1} soil and three different concentrations of SNP *viz*. N_0 = 0 mM SNP, N_1 = 0.1 mM SNP and N_2 = 0.2 mM SNP. The higher levels of As showed greater reduction of growth, development and yield component to control or without As. The different parameters such as plant height, leaf number $plant^{-1}$, number of tiller and effective tiller $plant^{-1}$, length of spike, number of spikelet $spike^{-1}$, number of effective spikelet $spike^{-1}$ number of grains $plant^{-1}$, 100-grains weight and grain yield pot^{-1} of wheat significantly decreased with As contamination.

Noor *et al.* (2016) recorded the performance of different wheat varieties on arsenic contaminated soil and irrigation water at field trials of Jessore (Chowgacha and Sharsha), Faridpur (Poranpur) and also at low contaminated Shatkhira (Benerpota). Five varieties of wheat viz. Shatabdi, Bijoy, Prodip, BARI Gom-25 and BARI Gom-26 were tested. Total arsenic contents in the soils were 36.4, 32.8, 28.5 and 6.8 mg kg^{-1} for Sharsha, Chowgacha, Poranpur and Benerpota, respectively. Irrigation waters contained 0.346, 0.272, 0.238 and 0.140 mg L^{-1} arsenic for Sharsha, Chowgacha, Poranpur and Benerpota, respectively. No significant variations in yield and yield components among the tested wheat varieties were observed despite of arsenic contaminations in the irrigation water and soil. The variety, Prodip contains 0.043 and 0.028 mg kg^{-1} arsenic in straw and grain, respectively, which was lower than the other tested varieties. But arsenic contents in all of the tested wheat varieties were found much lower than that of the permissible limit (1 mg kg^{-1}). The transfer coefficient (TC) of arsenic from soil to above ground parts (straw + grain) of wheat varied slightly among the tested varieties where Prodip showed the lowest TC (0.0015–0.0018).

Ziasmin (2016) conducted a pot experiment to assess the contribution of Salicylic acid (SA) on mitigation of Arsenic (As) toxicity in wheat. In this experiment, the treatment consisted of four different As levels *viz.* As_0 = without As (control), As_1 = 30 mg As kg^{-1} soil, As_2 = 60 mg As kg^{-1} soil, AS_3 = 90 mg As kg^{-1} soil and three different levels of SA *viz.* S_0 = 0 mM, S_1 = 0.2 mM and S_2 = 0.4 mM. The morpho-physiological, yield contributing characters and yield were noticeably affected by different levels of As. The greater amount of As caused greater reduction of growth which related to morphology and yield than control or without As. The morphological characters: plant height, number of leaves, tillers and effective tiller plant^{-1}; yield contributing characters: number of spikelets, effective spikelet spike^{-1}, spike length, number of grains spike^{-1}, grain yield plant^{-1} and 100-grains weight of wheat were noticeably decreased due to As toxicity. The grain yield was gradually decreased with the increasing level of As toxicity. The minimum grain yield·plant^{-1} were found 1.8 g, 1.5 g and 1.00 g at 30 mg, 60 mg, and 90 mg As kg^{-1} soil, respectively.

Akhtar and Shoaib (2014) conducted a pot experiment and observed damaging influence of arsenate (V) on germination and early growth of wheat (*T. aestivum* L.). Four concentrations of As (V) i.e. 0.013, 0.025, 0.038 and 0.05 mg pot^{-1}

were used to spike sandy loam soil. Different As (V) treatments in the soil resulted in significant reduction in germination rate (G%), germination index (GI) and relative germination rate (RGR), while increased in arsenic response index (ARI). Shoot growth and biomass were significantly declined by 40–90%, and that of roots were decreased by 50–99% in 2-week and 4-weeks old plants. Morphological symptoms like yellowing of leaf margins, stunt roots and stems were observed at higher dose (0.05 mg) of As (V) in 4-week seedling. The tolerance index (TI) of seedling was decreased and metal accumulation was increased that revealed increase in the seedling sensitivity with increasing concentrations of As (V). Root accumulated more metal than the shoots.

Liu *et al.* (2012) conducted a pot experiment to study the effects of high concentrations of soil arsenic on the growth of winter wheat (*T. aestivum* L) and rape (*Brassica napus*) with the soil As bioavailability at different growth stages of wheat and rape. The results indicated that winter wheat was much more sensitive to As stress than rape. Wheat yields were elevated at low rates of As addition (< 60 mg·kg^{-1}) but reduced at high rates of As concentrations (80–100 mg kg^{-1}). When soil As concentration was less than 60 mg kg^{-1}, both wheat and rape could grow satisfactorily without adverse effects; when soil As concentration was 80–100 mg kg^{-1}, rape was more suitable to be planted than wheat.

Zhang *et al.* (2009) conducted a field experiment on soil contamination on four wheat varieties (Jimai, Gaoyou, Weimai and Wennong) in Eastern China, using 50 or 100 mg arsenic·kg^{-1} soil. Results showed that addition of arsenic significantly reduced root, stem and spike dry weight and yield components, which resulted in the decrease of grain yield per plant. Arsenic concentrations in plant tissues increased significantly with treatments, and its uptake varied considerably among wheat varieties, plant tissues and arsenic treatments. Arsenic concentrations in plant tissues were as follows: roots > stems > leaves and rachises > grains > glumes > awns. In the arsenic treatments, arsenic concentrations in bran were about 2–3 times higher than those in flour. Most of the arsenic contaminated flour exceeded the Chinese tolerance limit. Arsenic contents of grain parts were dependent on variety and treatment level in polluted soils. Weimai and Wennong showed the highest amounts of arsenic in flour than the other varieties at 50 or 100 mg kg^{-1} soil treatment, respectively. Weimai possessed significantly lower amount of arsenic in bran than any other wheat variety.

Pigna *et al.* (2008) conducted an experiment to observe the influence of phosphate on the Arsenic uptake by Wheat (*Triticum durum* L.) irrigated with arsenic solutions at three different concentrations. They reported that decrease in plants biomass with increasing As concentration in irrigation water was less severe in added P conditions.

Li *et al.* (2007) carried out a research to study the effects of arsenic on seed germination and physiological activities of wheat seedlings. They reported that wheat being the second most important cereal crop in Bangladesh is cultivated in badly arsenic contaminated regions like Jessore and Faridpur. There is a general perception that upland crop like wheat may contain low amount of As than that of rice. The researchers reported that inappropriate arsenic concentrations can be harmful to wheat seedling at early developmental stages. Seed germination and seedling growth were stimulated at low and inhibited at high As concentrations (5–20 mg kg^{-1} soil). Physiological activities of wheat seedlings were also changed under As stress.

Liu and Zhang (2007) from their research work titled as ‘Intraspecific differences in effects of co-contamination of cadmium and arsenate on early seedling growth and metal uptake by wheat’ stated that seed germination, biomass, root length and shoot height decreased and As accumulation increased on early seedlings of six wheat varieties as concentrations of As increased.

Geng *et al.* (2006) from their experimental work titled as ‘Arsenate (As) uptake by and distribution in two cultivars of winter wheat (*T. aestivum* L.)’ stated that in winter wheat, As slightly reduces both root and shoot biomass. P supply slightly reduced root dry weights, but markedly increased shoot dry weights.

Gulz *et al.* (2005) observed that As had increased wheat yield significantly with 20.1% higher than the control when As addition was 60 mg kg^{-1}. When soil As concentration was ≥ 80 mg kg^{-1}, the wheat yield decreased significantly. The same tendency was seen with the weight of 1000-grains in wheat.

Liu *et al.* (2005) carried out an experiment to study the toxicity of arsenate and arsenite on germination, seedling growth and amylolytic activity of wheat. The researcher observed that there was a significant decline in root biomass production in wheat seedlings and grain yield with the increase in As (III) and As (V) concentrations for *T. aestivum.*

Ducsay (2000) conducted an experiment in laboratory conditions to investigate the impacts of upward doses of As, cadmium (Cd) and lead (Pb) on quality of cultivated biomass wheat (*T. aestivum* L.) during 21 days and production of chlorophyll a and chlorophyll b. The most expressive decrease of growth of crops was found in As, Cd and Pb. The increase of their concentrations in soil caused increasing of their concentration in biomass.

National Food Authority (1993) reported that As concentrations of wheat and rape in grain increased with arsenic added in soil but did not exceed the maximum permissible limit for food stuffs of 1.0 mg kg^{-1}.

2.2 Effect of vermicompost on wheat

Hadis *et al*. (2018) conducted a greenhouse pot experiment to determine the effects of vermicompost, inorganic fertilizers and their combinations on nutrient uptake, yield and yield components of wheat. Four levels (0, 2, 4 and 6 t·ha^{-1}) of vermicompost and four levels (0, 33.33, 66.67 and 100%·ha^{-1}) of the recommended NPK fertilizers were used. Bread wheat variety, Kekaba was used as a test crop. Vermicompost applied at 2, 4 and 6 t·ha^{-1} increased grains yield of wheat by 11, 17 and 26% over control respectively whereas 33.33, 66.67 and 100% NPK fertilizers increased the grain yield by 10, 24 and 30%, respectively over the control. Vermicompost applied at 6 t·ha^{-1} resulted in the highest nutrient uptake and it increased grain uptake of N, P and K by 51, 110 and 89% over control respectively whereas among fertilizer rates, the highest uptake was produced by 100% NPK treatment and it increased the N, P and K uptake in the grain by were 79, 100 and 96% over control, respectively.

Rai *et al.* (2017) conducted two consecutive field experiments after rice crop during 2011–12 and 2012–13 to evaluate the residual effect of vermicompost and applied inorganic fertilizers on wheat crop. Ten different treatments were used in this experiment which were as follows: T_1 - Control without NPK in rice and wheat, T_2 - 100% RDF to rice and wheat, T_3 - 75% N + 100% P and K + Vermicompost @ 2 t·ha^{-1} as basal to rice followed by 100% RDF to wheat, T_4 - 75% N + 100% P and K + Vermicompost @ 2 t ha^{-1} at tillering stage to rice followed by 100% RDF to wheat, T_5 - 75% N + 100% P and K + Vermicompost @ 2 ton·ha^{-1} at panicle initiation followed by 100% RDF to wheat, T_6 - 75% N + 100% P and K + Vermicompost @ 2 t ha^{-1} at flowering stage to rice followed by 100% RDF to wheat, T_7 - 50% N + 100% P and K + Vermicompost @ 4 ton·ha^{-1} as basal to rice followed by 100% RDF to wheat, T_8 - 50% N + 100% P and K + Vermicompost @ 4 t ha^{-1} at tillering stage to rice followed by 100% RDF to wheat, T_9 - 50% N + 100% P and K + Vermicompost @ 4 t ha^{-1} at panicle initiation to rice followed by 100% RDF to wheat and T_{10} - 50% N + 100% P and K + Vermicompost @ 4 t ha^{-1} at flowering stage to rice followed by 100%

RDF to rice. RDF for rice 120 kg ha^{-1} of N, 60 kg ha^{-1} of P and 60 kg ha^{-1} of K while for wheat 150 kg ha^{-1} of N, 75 kg ha^{-1} of P and 60 kg ha^{-1} of K for both the years. Significantly taller plants than T_2 during both the years were measured in those treatments where 4 ton vermicompost was applied in rice. Spike length and test weight of wheat remained unaffected due to residual effect while the number of grains per spike was significantly affected. Grain yield varied from 20.00 to 48.70 and 21.30 to 49.50 q ha^{-1} during 2011–12 and 2012–13, respectively while straw yield 36.35 to 71.24 and 39.53 to 73.04 q ha^{-1} during 2011–12 and 2012–13. The maximum grain yield 48.70 and 49.50 q ha^{-1} during 2011–12 and 2012–13, respectively and straw yield 71.24 and 73.04 q ha^{-1} was recorded in T_{10} where along with 50% N + 100% P + 100% K, 4 ton vermicompost was applied in rice at flowering and 100% NPK to wheat.

Samad (2017) carried out a field experiment to study the effect of vermicompost on growth and yield of wheat under different moisture regimes with the variety, BARI Gom 26. The experiment comprised of four levels of irrigation *viz*., I_0 = No irrigation (control), I_1 = Irrigation at18 days after sowing (DAS), I_2 = Irrigation at 18 and 47 days after sowing (DAS) and I_3 = Irrigation at 18, 47 and 76 days after sowing (DAS) and three levels of vermicompost *viz*., V_0 = No vermicompost (control), V_1 = Vermicompost @ 5 t ha^{-1} and V_2 = Vermicompost @ 10 t·ha^{-1}. It was found that V_2 (Vermicompost @ 10 t ha^{-1}) gave the best performance in respect of growth, yield and yield attributes in wheat.

Dastmozd *et al*. (2015) conducted the study which explored the effect of vermicompost fertilizer as a biological agent compared with NPK fertilizers on yield and yield components of wheat to enhance the qualitative and quantitative yield. The results showed that application of 1800 kg ha^{-1} vermicompost with 80 kg ha^{-1} NPK fertilizers improved grain yield and wheat morphological and physiological characteristics significantly such as 1000-grain weight, plant height, number of spikes per hectare, number of grains per spike, and harvest index. The results of the experiments also indicated that vermicompost fertilizer can improve soil productivity and soil quality.

Ibrahim *et al*. (2015) conducted a study to investigate the effect of vermicompost and its mixtures with water treatment residuals on selected physical properties of saline sodic soil and on yield of wheat. The treatments were vermicompost, water treatment residuals, vermicompost + water treatment residuals (1∶1 and 2∶1 wet weight ratio) at levels of 5 and 10 g dry weight kg^{-1} dry soil. The addition of vermicompost and water treatment residuals had improved the grain yield of wheat. The treatment of (2 vermicompost + 1 water treatment residuals) at level of 5 g kg^{-1} soil gave the best grain yield. The application of vermicompost and water treatment residuals to improve the physical properties in the salt affected soils is a promising technology to meet the requirements of high plant growth and cost-effective reclamation.

Yousefi and Sadeghi (2014) conducted a study to investigate the effect of different doses of vermicompost organic fertilizer on chemical fertilizer urea reduce and its impact on the yield and yield components. The treatments included three levels of vermicompost organic fertilizer (5, 10 and 15 t ha^{-1}) and five levels of urea chemical fertilizer (0, 25, 50, 75 and 100% the recommended rate based on soil test). The results indicated that the combined application of urea fertilizer, organic fertilizer vermicompost had significant effects on grain yield and grain weight. The maximum yield was reported from the treatments of 100% of the recommended urea with 10- and 15-ton·ha^{-1} vermicompost and treatments recommended by 75% urea + 15-t ha^{-1} vermicompost, respectively, which is statistically similar, i.e. there was no significant difference among the three groups (4977.3, 4890.7 and 4953.0 kg ha^{-1}, respectively). Thus, it was concluded that the application of vermicompost organic fertilizer, can reduce chemical fertilizer urea up to 25%.

Kizilkaya *et al.* (2012) carried out an experiment to study the effects of vermicompost on wheat (*T. aestivum*) yield and nutrient content in soil and plant. Ability of the earthworm *Eisenia foetida* to transform anaerobically digested sewage sludge (SS) amended with hazelnut husk (HH) and cow manure (CM) in different proportions (0% SS + 50% HH + 50% CM; 10% SS + 45% HH + 45%

CM; 20% SS + 40% HH + 40% CM; 30% SS + 35% HH + 35% CM; 40 SS% + 30% HH + 30% CM; 50% SS + 25% HH + 25% CM) was studied. Spring wheat (*T. aestivum*) cv Pandas seeds were sown. All vermicomposted and non-vermicomposted mixtures exhibited positive effect on the yield and nutrient concentrations of wheat compared to the control treatments. The vermicomposted organic waste mixtures showed comparatively better effect on plant production than the non-vermicomposted organic waste mixtures. Increase in wheat grain and straw yield and nutrient content in plant and soil was significantly more in vermicomposted OW mixtures than in non-vermicomposted OW mixtures, indicating a synergistic effect between wheat and vermicompost. Vermicomposted 50% SS + 25% HH + 25% CM mixtures showed the highest positive effect on yield compared to the other treatments.

Zhou and Chen (2011) observed that weight of 1000-grains increased in wheat by mixing of worm cast with ^{15}N labeled chemical fertilizers.

Channabasanagowda *et al.* (2008) conducted an experiment to observe the effect of organic manures on growth, seed yield and quality of wheat. They reported that application of vermicompost @ 3.8 t ha^{-1} + poultry manure @ 2.45 t ha^{-1} in wheat, recorded significantly higher plant height (86.30 cm), number of leaves (60.10 leaf plant^{-1}), 1000-seed weight (42.73 g) and seed yield (3043 kg ha^{-1}), vigor index (3223), seedling dry weight (311.27 mg plant^{-1}) and protein content (13.41%) compared to other treatments.

Nehra *et al.* (2007) set up an experiment to study the effect of integrated nutrient management on growth and yield of wheat. Application of FYM at 15 t ha^{-1}, vermicompost at 10 and 15 t ha^{-1} and press mud at 2.5 and 5 t ha^{-1} increased grain yield by 27.5, 28.5, 46.7, 13.6 and 27.3% during 1997–98, and by 20.8, 23.2, 40.9, 11.9 and 19.1% during 1998–99, respectively, over no organic manure application.

Khandwe *et al*. (2006) carried out a field experiment to evaluate the effect of vermicompost and NPK on wheat yield (*T. aestivum*). Wheat variety Malwa Shree (HI 83-81), Malwa Shakti (HI 84-98) and JW-17 combine with basal dose of vermicompost 3 t·ha^{-1} and 50% recommended dose of NPK showed significant differences over to vermicompost alone treatment and control (No use of NPK). While treatment 100% recommended dose of NPK gave par results. Treatment vermicompost 3 t ha^{-1} gave significant differences over control.

Patil and Bhilare (2006) reported that application of vermicompost prepared from locally available organic materials (wheat straw, press mud cake and FYM, application of press mud cake (PMC) 50% + FYM 50%) recorded the tallest plant (92 cm), maximum number of tillers·plant^{-1} (3) and highest seed yield (39 q·ha^{-1}) in wheat over application of these manures separately.

Bhuiyan (2005) conducted a field experiment to study the effect of vermicompost and NPK on the growth. chemical composition and yield of wheat. The treatments were 4 levels of vermicompost's viz. V_0 (0 t·ha^{-1}), V_1 (1 t ha^{-1}), V_2 (2t ha^{-1}), V_3 (3 t ha^{-1}), and 4 levels of chemical fertilizers *viz.* F_0 = (0-0-0 kg ha^{-1}), F_1 = low (40-30-20 kg ha^{-1}), F_2 = medium (50-60-40 kg ha^{-1}) and F_3 = high (120-80-60 kg ha^{-1}) of N-P_2O_5-K_2O. The results demonstrated that with the increasing the doses of vermicompost and chemical fertilizers increased grain and straw yield of wheat significantly. The maximum significant grain and straw yields were obtained with the treatment combinations V_3F_2 or V_2F_3. The highest doses of vermicompost and chemical fertilizers increased N, P, K and S concentrations in wheat plant significant at different stages of plant growth and also enhanced N, P, K and S uptake significantly at the ripening stage. Application of chemical fertilizers failed to increase organic matter content of post-harvest soil, whereas vermicompost showed a significant positive effect.

Singh and Singh (2005) conducted an experiment to investigate the effect of organic manures and herbicides on yield and yield-attributing characters of wheat. They recorded significantly higher grain and biological yields with VC at

15 t ha^{-1}, over other treatments except that grain yield obtained with VC at 10- and 15-t ha^{-1} were statistically at par. Overall, the increase in grain yield was 29.91, 18.81, 35.44 and 45.21% owing to FYM 15 t ha^{-1} and VC 7.5, 10- and 15-t ha^{-1} over no organic manure, respectively. The harvest index was not influenced significantly by the application of organic manures. The application of organic manures improved the yield attributing characters, grain and biological yields compared to no organic manure. However, grains ear^{-1} remained unaffected by various organic sources of nutrients. An increase of 6.83, 5.20, 9.57 and 15.56% in number of effective tillers, and 8.3, 3.61, 8.40 and 12.65% in grain weight ear^{-1} was observed in pooled data with FYM at 15 tons·ha^{-1}, vermicompost at 7.5, 10 and 15 t ha^{-1} over no organic manure, respectively. The effect of vermicompost at 10 tons and FYM at 15 t ha^{-1}, being statistically at par with each other, were superior to no organic manure during both the years in respect of yield-attributing characters.

Yadav *et al.* (2005) carried out a research work to study the effect of integrated nutrient management on rice (*Oryza sativa*) and wheat (*T. aestivum*) cropping system. They reported that application of vermicompost increased grain yield in wheat.

Kumar *et al*. (2004) from their experimental work reported that significantly higher amount of dry matter production was recorded with the application of vermicompost @ 2 to 4 t ha^{-1} and was on par with FYM @10 t ha^{-1}. This might be attributed to the increased uptake of available nutrients which caused increased photosynthetic rate resulting in higher dry matter production.

Agrawal *et al.* (2003) carried out an experiment to study the effect of vermicompost, farm yard manure and chemical fertilizers on growth and yield of wheat (*T. aestivum* L. var. HD 2643). Application of vermicompost and farm yard manure in combination showed significantly increased biomass production and positive effect on yield parameters of wheat. Plant height, Spikelets $plant^{-1}$, number of seeds $spike^{-1}$, test grain weight, harvest index (HI) and grain yield pot^{-1} were recorded maximum in treatment T_7 [VC (75%) + FYM (25%)] and the magnitude of increase HI and grain yield was from 39.67% and 2.80 g pot^{-1} in T_0 to 44.76% and 4.51 g pot^{-1} T_7, respectively.

Kanwar (2002) reported that application of organic manure i.e. vermicompost or FYM along with fertilizer NPK had beneficial residual effect in increasing yield, uptake of nutrients in wheat crop as well as available nutrient (NPK) in soil. The best treatment i.e. 50% NPK fertilizer along with vermicompost @ 10 t ha^{-1} was tested in farmers' fields.

Khandal and Nagendra (2002) conducted a study on two wheat cultivars to investigate the effect of chemical fertilizers (NPK fertilizer) and organic manure (vermicompost). Results showed that plant height, dry matter production and grain yield were higher at higher dose of vermicompost. Number of tillers and leaves per plant were very low at early stages of growth and suddenly increased after adding different concentrations of vermicompost and organic manure.

Ranwa and Singh (1999) conducted a field experiment during the winter seasons of 1994–96 to study the effect of integration of nitrogen with vermicompost on wheat crop. The treatment comprised 5 levels of organic manures, viz., no organic manure, farmyard manure at 10 t ha^{-1}, vermicompost (at 5, 7.5 and 10 t ha^{-1}) and 5 levels of N viz. 0, 50, 100, 150 kg ha^{-1} and recommended fertilizer. They reported that the application of organic manures improved yield attributes and grain, straw and biological yields of wheat. Application of vermicompost at 7.5 or 10 t ha^{-1} resulted in higher yields than 10 t ha^{-1} FYM.

Steel *et al.* (1997) observed the increased shoot and root dry weight of wheat plants in the presence of earthworms.

Kang and Juo (1986) from their experiment titled as 'Effect of forest clearing on soil chemical properties and crop performance' reported positive influence of worm cast on the shoot fresh biomass of wheat seedlings.

2.3 Interaction of arsenic and vermicompost on wheat growth, yield contributing and yield parameters

Karmakar *et al.* (2021) conducted an experiment to observe whether zinc sulphate and vermicompost can mitigate phytotoxic effects of arsenic by altering arsenic uptake, biochemical and antioxidant enzyme activities in wheat (*T. aestivum* L.). Seedlings of wheat genotype HUW-234 (*T. aestivum* L.) were raised in pot soil culture using eight different treatment combinations, enriched with inorganic arsenic (As at 0, 30 $mg \cdot kg^{-1}$ soil), zinc sulphate (Zn at 0, 20 $mg \cdot kg^{-1}$ soil) and vermicompost (at 0, 15 t ha^{-1}). Plants exposed to As toxicity were found significantly lower in total chlorophyll, carotenoids and soluble protein content and higher in proline accumulation. A significant reduction in nitrate reductase (NR) activity was also noticed under this As stress. As toxicity severely altered the activities of several antioxidant scavenging enzymes in the test seedlings. Superoxide dismutase (SOD) and ascorbate peroxidase (APX) activities were found elevated, whereas, catalase (CAT) showed a decrease in its activity in seedlings exposed to As stress. As a consequence, a significant ($P \leq 0.05$) reduction in grain yield (up to 42%) was also recorded. Mitigation of toxic effects of As with significant alteration in the biochemical constituents, as well as antioxidant enzymatic activities, was observed when supplemented with zinc sulphate and vermicompost whether alone or in combination. All these examined parameters were correlated either positively or negatively with the concentrations of As in wheat grain, straw and root. The rate of translocation of As in plants was increased when solely treated with As; while a decreasing trend was noticed for those plants which received zinc sulphate and vermicompost as treatment. Hence, this study faithfully established the relationship of zinc sulphate and vermicompost application with reduced As content in the plant part, thus resulting in better crop growth and yield.

Raj *et al.* (2020) conducted a study to determine the efficacy of organic amendment in reducing arsenic uptake in wheat. For this purpose, soil was collected and recommended dose of N, P, K were added. The soil was spiked with five different level of arsenic (0, 10, 20, 30, 40 ppm). For organic amendment paddy husk and vermicompost were used. The treatments were three levels of vermicompost at 10 t ha^{-1} and rice husk given at 10 t ha^{-1}. The recommended doses of NPK in the form of solution 150:60:40 kg ha^{-1} were applied to the soils irrespective of treatment. Treatments combinations which were used in the experiment as follows: Arsenic doses + Organic sources, T_1: 0 ppm + Control (No amendment); T_2: 0 ppm + Paddy Husk; T_3: 0 ppm + Vermicompost; T_4: 10 ppm + Control (No amendment); T_5: 10 ppm + Paddy Husk; T_6: 10 ppm + Vermicompost; T_7: 20 ppm + Control (No amendment); T_8: 20 ppm + Paddy Husk; T_9: 20 ppm + Vermicompost; T_{10}: 30 ppm + Control (No amendment); T_{11}: 30 ppm + Paddy Husk; T_{12}: 30 ppm + Vermicompost; T_{13}: 40 ppm + Control (No amendment); T_{14}: 40 ppm + Paddy Husk and T_{15}: 40 ppm + Vermicompost. Wheat seeds variety 'HD-2733' were sown in the pots. The treatments were found to be statistically significant. Amendments with paddy Husk 10 t ha^{-1} proved to be the best causing considerable reduction in available arsenic with respect to control followed by vermicompost @ 10 t ha^{-1}, 16% decrease in available arsenic was found with paddy husk amendments followed by 5% reduction with vermicompost with respect to control. An overall 12.5% decrease in available arsenic has been recorded against paddy husk with respect to vermicompost. Accumulation of As increased with the increase in the graded dose of As from 0 ppm (control) to 18.21 ppm in 40 ppm dose. Application of amendments resulted in reduction of As accumulation high in paddy husk (17% with respect to control) followed by vermicompost (6% with respect to control), depicts the interaction effect, which are found to be statistically significant. Amendments with paddy husk found to be effective in reducing As accumulation in grain with respect to other treatments irrespective of the levels of As. A considerable reduction in grain dry matter weight was observed with the increase in the levels of As. The maximum dry matter weight of grain per pot of 24.01 g is recorded against control and maximum of 10.25 g against 40 ppm As. Addition of paddy husk As an amendments proved to be the best in increasing the dry matter weight of grain irrespective of the doses of As compared to vermicompost. 10.18% increase of grain dry matter weight per pot in paddy husk with respect to control treatments. And in vermicompost 8.73% grain dry matter weight is increased as compared no treatments. Whereas 1.31% increase of grain dry matter weight against paddy husk with respect to vermicompost. The results revealed that the treatment with the paddy husk was found to be the best in comparison to vermicompost for amendment of arsenic. The arsenic accumulation in plants parts followed the order root > stem > leaf > economic produce and it was found that paddy husk was the better amendment for all the arsenic accumulated plant parts.

Karmakar and Prakash (2019) illustrated the phytotoxicity of arsenic (As) on wheat (HUW-234) seedlings and pre-application of zinc sulphate and vermicompost for mitigating toxic effects of As. Seedlings of HUW-234 genotype of wheat (*T. aestivum* L.) were raised in pot soil culture using eight treatment combinations viz., Control, Vermicompost @ 15 $t \cdot ha^{-1}$, $ZnSO_4.7H_2O$ @ 20 ppm Zn, Vermicompost @ 15 t ha^{-1} + $ZnSO_4.7H_2O$ @ 20 ppm Zn, $Na_2HAsO_4.7H_2O$ @ 30 ppm As, $Na_2HAsO_4.7H_2O$ @ 30 ppm As + Vermicompost @ 15 $t \cdot ha^{-1}$, $Na_2HAsO_4.7H_2O$ @ 30 ppm As + $ZnSO_4.7H_2O$ @ 20 ppm Zn and $Na_2HAsO_4.7H_2O$ @ 30 ppm As + Vermicompost @ 15 t ha^{-1} + $ZnSO_4.7H_2O$ @ 20 ppm Zn. Perusal of data indicated that arsenic @ 30 ppm treated pots showed decrease in plant height, leaf area and shoot dry matter as compared to pots with no arsenic treatment. Zinc @ 20 ppm and Vermicompost @ 15 t ha^{-1} alone resulted in increase in plant height, leaf area and shoot dry matter. The highest plant height, leaf area and shoot dry matter in arsenic treated pots were found in treatment supplemented with Zinc @ 20 ppm and Vermicompost @ 15 t ha^{-1}, whereas, least of above parameters were recorded in pots without zinc and vermicompost supplementation. There was slight non-significant decrease in number of ears per plant in wheat due to arsenic treatment. Number of grains per ear, test weight and grain yield reduced significantly due to arsenic treatment. The interaction of Arsenic × Zinc, Arsenic × Vermicompost and Arsenic × Zinc × Vermicompost was found to be significant for number of grains per ear, test weight and grain yield and there was significant increase in number of grains per ear, test weight and grain yield, indicating zinc and vermicompost reducing the toxic effects of arsenic. The decrease in yield parameters and yield due to arsenic treatment could be due to effect of arsenic on altering metabolic enzyme activities, thus reduced morphological parameters such as leaf area and shoot dry matter, reduction in chlorophyll activity in the present experiment.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the materials and methods of the experiment with a brief description on experimental site, climate, soil, land preparation, planting materials, experimental design, fertilizer application, irrigation and drainage, intercultural operation, data collection, data recording and their analysis. The details of investigation for achieving stated objectives are described below.

3.1 Experimental period

The experiment was conducted at the net house of the Department of Agronomy, Sher-e-Bangla Agricultural University during the period from November, 2019 to March, 2020.

3.2 Geographical location

The experimental site was located at 23°46′ N latitude and 90°23′ E longitude with an altitude of 8.45 m.

3.3 Agro-Ecological Region

The experimental site belongs to the agro-ecological zone of "Madhupur Tract", AEZ-28. This was a region of complex relief and soils developed over the Madhupur clay, where floodplain sediments buried the dissected edges of the Madhupur Tract leaving small hillocks of red soils as 'islands' surrounded by floodplain (FAO-UNDP, 1988). For better understanding, the experimental site is shown in the AEZ Map of Bangladesh in Appendix I (A).

3.4 Climate and weather

The geographical location of the experimental site was under the sub-tropical climate characterized by three distinct seasons. The monsoon or rainy season extending from May to October, which is associated with high temperature, high humidity and heavy rainfall. The winter or dry season from November to February, which is associated with moderately low temperature and the premonsoon period or hot season from March to April ,which is associated with less rainfall and occasional gusty winds. Information regarding monthly maximum and minimum temperature, rainfall, relative humidity and sunshine during the period of study of the experimental site was collected from Bangladesh Meteorological Department, Agargaon and is presented in Appendix II.

3.5 Soil

The soil of the experimental area was silty clay in texture, red brown terrace soil type, olive–grey with common fine to medium distinct dark yellowish-brown mottles. Soil pH was 5.5 and had organic carbon 0.43% [Appendix II(B)]. The land was well drained with good irrigation facilities. The experimental site was a medium high land. It was above flood level and sufficient sunshine was available during the experimental period. The morphological characters of soil of the experimental plots are as following - Soil series: Tejgaon, General soil: Non-calcareous dark grey [Appendix I (B)]. The physicochemical properties of the soil are presented in Appendix II.

3.6 Planting materials

An improved variety of wheat - BARI Gom-23 (Bijoy) was used as planting material for the present study. The variety is recommended for rabi season. The seeds were collected from BARI. The feature of the variety is presented below:

Name of Variety : BARI Gom-23 (Bijoy)
Height : 95–105 cm, semi-dwarf
Maturity : 103–112 days
Number of grains spike^{-1} : 35–40
Grain appearances : White, glossy and small size
1000 grains-weight : 24–28 g
Yield : 4.30–5.00 t ha^{-1}

3.7 Treatments

The experiment consisted of two sets of treatments. The treatments were arsenic concentrations and vermicompost doses. Those are shown below:

Factor A: Arsenic concentrations (3)

i. A_0: Control (No Arsenic)
ii. A_1: 25 mg As kg^{-1} soil
iii. A_2: 50 mg As kg^{-1} soil

Factor B: Vermicompost doses (3)

i. V_0: Control (No Vermicompost)
ii. V_1: 2.50 t ha^{-1}
iii. V_2: 5.00 t ha^{-1}

3.8 Experimental design

The experiment was laid out in a Completely Random Design (CRD) with six (6) replications. Total 54 unit-pots were prepared for the experiment. Each pot was of required size.

3.9 Collection and preparation of soil

The soil of the experiment was collected from Sher-e-Bangla Agricultural University (SAU) farm. The soil was non-calcareous Red Brown Terrace soil with loamy texture belonging to the AEZ Madhupur Tract. The collected soil was pulverized and inert materials, visible insect pest and plant propagules were removed. The soil was dried in the sun, crushed carefully and thoroughly mixed.

3.10 Sterilization of seed

Prior to germination seeds were surface sterilized with 1% sodium hypochlorite solution. The glass vials containing distilled water for seed rinsing was sterilized for 20 minutes.

3.11 Preparation of pots and experimental design

The plants were grown in pots and the soil was used as growth medium. Chemical fertilizers namely urea, triple supper phosphate (TSP), muriate of potash (MoP) and gypsum at the rate of 175, 150, 210 and 125 kg ha^{-1}, respectively were applied for N, P, K and S. Soils of 12 kg pot^{-1} were fertilized with 1.05 g urea pot^{-1}. 0.9 g TSP pot^{-1}, 0.66 g MoP pot^{-1}. All TSP, MP and one-third of the urea were applied as basal dose. The remaining two-third of the urea dose was applied in each pot at 24 and 46 days after sowing (DAS) of wheat. Each pot was 21 cm deep with 24 cm diameter at the top were used. Vermicompost were applied in designated pots as per treatment which are given in 3.7 of this chapter. The pots were prepared on 18 November 2019 and fertilization were done on 20 November 2019. Considerable spacing was maintained among pots for convenience of cultural operation. Thereafter the pots containing soil were moistened with water.

3.12 Sowing of seeds in pot

The sterilized seeds were soaked with water for 24 hours, washed thoroughly in clean water and incubated for sprouting, which were sown in the pots on 21 November 2019. First germination was seen on 25 November 2019. Seed were sown in broadcasting method with a seed rate of 120–140 kg ha^{-1}. In total, 53.676 g seeds were needed in this experiment.

3.13 Application of arsenic

Wheat plants were treated with 25 mg As kg^{-1} soil (0.25 g) and 50mg As kg^{-1} soil (0.5 g) of arsenic (As) with sodium arsenite salt. In the experiment, As was used in the form of sodium arsenite (Na_3AsO_3), which was collected from local market. For 25 mg As kg^{-1} soil, 25 mg As was mixed with 1 kg soil. In a single pot, 250 ml water was required for making arsenic solution. Each pot contains 12 kg soil, for 18 pots which was treated with 25 ppm solution needed 4.5 L water in total and (25 × 12 × 18) mg = 5400 mg = 5.4 g As in total. For 50 ppm, 50 mg As was mixed with 1 kg soil. In a single pot, 250 ml water was required for making arsenic solution. Each pot contains 12 kg soil, for 18 pots which was treated with 50 ppm solution needed 4.5 L water in total and (50 × 12 × 18) mg = 10800 mg = 10.8 g As in total. The solution was used as irrigation water to irrigate the designated pots at 19 December 2019. The soil was fully rotated once to mixture the arsenic well.

3.14 Intercultural operation

Weeds grown in the pots were removed time to time in order to keep the pots weed and pest free. The soil was loosened whenever necessary during the period of experiment. Watering was done in each pot to hold the soil water level and salt concentration when needed.

3.15 Plant protection measures

The crop was protected from birds and rats during the grain-filling period. Zinc phosphide was applied to control rat. Net was given to protect the wheat grain from bird especially Parrots.

3.16 Harvesting and post-harvest operation

The wheat plants were harvested depending upon the maturity at 109 DAS. Harvesting was done manually from each pot on 9 March 2019. Maturity of crop was determined when 80% of the grains became white shiny in colour. The selected sample plants were then harvested, bundled, tagged and carefully carried to the threshing yard in order to collect data. The crop bundles were sun dried by spreading those on the threshing floor. The grains were separated from the plants by beating the bundles with bamboo sticks. Fresh weight of grain and straw were recorded pot wise. The grains were cleaned and sun dried for 3 days. Straw was also sun dried properly. Properly dried grain and straw were weighed and converted into g plant^{-1} basis.

3.17 Recording of plant data

The growth parameters during study were recorded at 15 days interval started from 30 DAS up to 60 DAS from plants grown in the pot while the yield data and other parameters were taken at harvest.

3.17.1 Crop growth parameters

a) Plant height
b) Number of tillers plant^{-1}
c) Root length

3.17.2 Yield contributing parameters

a) Number of grains spike^{-1}
b) Number of spikelets plant^{-1}
c) Spike length
d) Weight of 100-grains

3.17.3 Yield parameters

a) Grain yield plant^{-1}
b) Straw yield plant^{-1}
c) Biological yield plant^{-1}
d) Harvest index

3.18 Collection of data

3.18.1 Crop growth characters

3.18.1.1 Plant height measurement

The plant height of wheat plant was considered from the top surface level of the pot to the tip of the longest leaf at booting stage and flowering stag: At maturity stage the plant height of wheat plant was measured from the top surface level of the pot to the tipper end of the longest spike. Plant height was measured three growth stages (30 DAS, 45DAS, 60 DAS) and at harvest.

3.18.1.2 Tillers number plant^{-1}

Number of tillers plant^{-1} was counted at 30, 45 and 60 DAS by counting total tillers within a plant selected at random from each pot.

3.18.1.3 Root length

The length of root was measured with a meter scale from 3 selected roots plant^{-1} and the average value was recorded. The length was measured from the base of the plant at soil level to the to the tip of the root.

3.18.2 Yield contributing characters

3.18.2.1 Number of grains spike^{-1}

The total number of grains spike^{-1} was collected randomly from grains of 3 spikes plant^{-1} and then average number of grains spike^{-1} of wheat plant was recorded.

3.18.2.2 Number of spikelets plant^{-1}

The number of spikelets plant^{-1} was collected randomly from spikelets of 3 plants from the pots and then average number of spikelets plant^{-1} was recorded.

3.18.2.3 Spike length

The length of spike was measured with a meter scale from 3 selected spikes per plant and the average value was recorded.

3.18.2.4 Weight of 100-grains

One hundred cleaned dried grains were counted randomly from each pot and weighed by using a digital electric balance when the grains retained 12% moisture and the mean weight was expressed in gram.

3.18.3 Yield characters

3.18.3.1 Grain yield plant^{-1}

After proper drying, the grain yield plant^{-1} was recorded, which had effective tillers from each pot and expressed on 12% moisture basis. Grain moisture content was measured by using a digital moisture tester.

3.18.3.2 Straw yield plant^{-1}

Straw yield was determined from each pot, after separating the grains. The sub-samples were oven dried to a constant weight.

3.18.3.3 Biological yield plant^{-1}

Biological yield was determined using the following formula:
Biological yield (g plant^{-1}) = (Grain yield + Straw yield) g plant^{-1}

3.18.3.4 Harvest index

Harvest Index denotes the ratio of economic yield to biological yield. Harvest index was determined with the following formula of Donald (1963):

$$\text{Harvest Index (\%)} = \frac{\text{Economic Yield (Grain weight)}}{\text{Biological Yield (Total dry weight)}} \times 100$$

It was expressed in percentage.

3.19 Statistical analysis

The collected data on different parameters were compiled and analysed following the analysis of variance (ANOVA) techniques by CRD to find out the statistical significance of experimental results. The collected data were analysed by computer package program MSTAT-C software (Russell, 1986). The significant differences among the treatment means were compared by Least Significant Difference (LSD) at 5% levels of probability.

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to find out the effect of vermicompost on wheat at different arsenic level. The results obtained from the study have been presented, discussed and compared in this chapter through tables and graphs. The results have been presented and discussed with the help of tables and graphs and possible interpretations given under the following headings. The analytical results have been presented in Table 1 through Table 5 and Figure 1 through Figure 10.

4.1 Growth attributes of wheat

4.1.1 Plant height

4.1.1.1 Effect of vermicompost

Plant height of wheat showed significant variation due to effect of different levels of vermicompost at different data recording intervals (Figure 1). The tallest plant at 30 DAS (28.28 cm), 45 DAS (34.75 cm) and 60 DAS (39.06 cm) was recorded from the treatment V_1 (2.5 t ha^{-1}) while the tallest plant at harvest (63.07 cm) was obtained from the treatment V_0 (0 t ha^{-1}). On the other hand, the shortest plant at 30 DAS (27.71 cm), 45 DAS (33.01 cm) and at harvest (60.96 cm) was reported from the treatment V_2 (5.0 t $ha^{-1)}$ while at 60 DAS the shortest plant (37.97 cm) was observed in control treatment (V_0). The results of this study were in conformity with the findings of Karmakar and Prakash (2019), Rai *et al.* (2017), Dastmozd *et al*. (2015), Channabasanagowda *et al.* (2008), Patil and Bhilare (2006), Agrawal *et al.* (2003) and Khandal and Nagendra (2002) who mentioned that vermicompost application increased plant height of wheat.

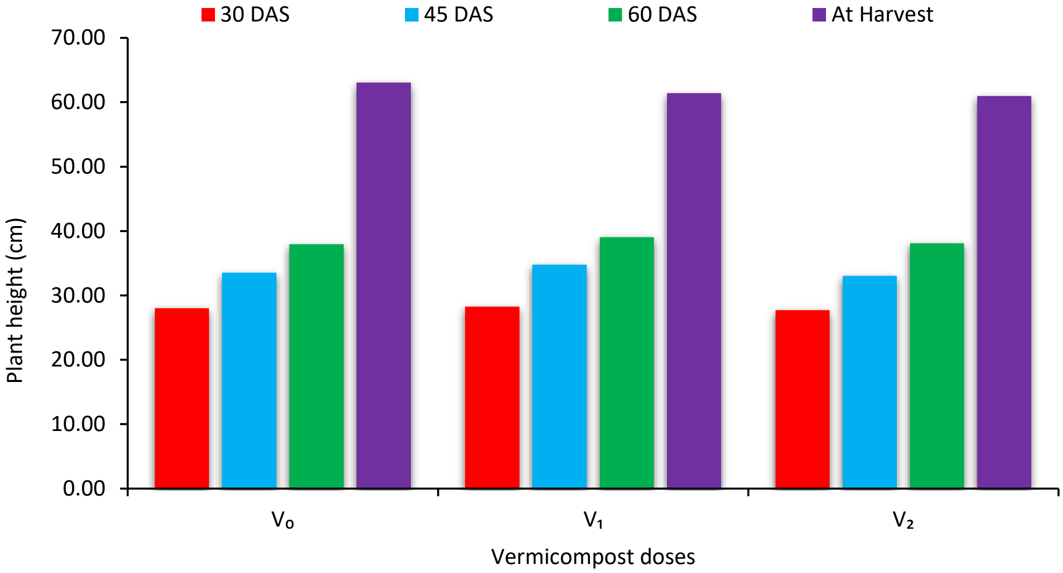

Figure 1. Effect of vermicompost doses on plant height at different data recording intervals of wheat. (LSD $_{0.05}$ = 0.989, 1.525, 1.310 and 3.292 at 30, 45, 60 DAS and at harvest, respectively).

$V_0 = 0$ t ha^{-1}, $V_1 = 2.5$ t ha^{-1} and $V_2 = 5.0$ t ha^{-1}

4.1.1.2 Effect of arsenic level

Different concentration of arsenic application exerted significant effect on plant height of wheat (Figure 2). At 30 DAS, 45 DAS, 60 DAS and at harvest, the tallest plant of wheat (28.57 cm, 34.68 cm, 39.14 cm and 64.52 cm, respectively) was observed in control treatment (A_0). On contrary, the shortest plant at 30 DAS, 45 DAS, 60 DAS and at harvest (27.17 cm, 32.02 cm, 37.03 cm and 60.64 cm, respectively) was recorded from the treatment A_2 (50 mg As kg^{-1} soil). This result was supported by the findings of Karmakar and Prakash (2019), Jahan (2016) and Ziasmin (2016) who stated that arsenic had detrimental effect on plant height of wheat.

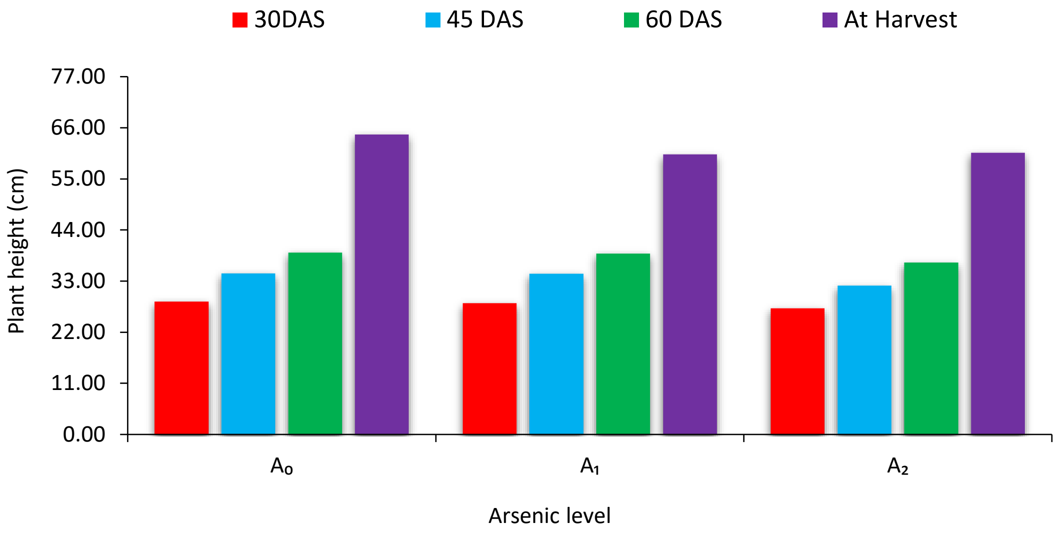

Figure 2. Effect of arsenic level on plant height of wheat at different data recording intervals of wheat. ($LSD_{0.05}$ = 0.989, 1.525, 1.310 and 3.292 at 30, 45, 60 DAS and at harvest, respectively).

A_0 = control (No arsenic), A_1 = 25 mg As kg^{-1} soil A_2 = 50 mg As kg^{-1} soil

4.1.1.3 Interaction effect of vermicompost and arsenic level

Interaction effect of different doses of vermicompost and different concentration of arsenic showed significant variation on plant height of wheat at different data recording intervals (Table 1). At 30 DAS, the tallest plant (29.43 cm) was observed from the V_2A_0 treatment combination which was statistically similar to V_1A_1 and V_0A_1 (29.29 cm and 28.56 cm, respectively). On the other hand, the shortest plant (26.81 cm) was recorded from V_2A_2 treatment combination which was statistically similar to V_0A_2 and V_2A_1 (27.17 cm and 26.90 cm, respectively). At 45 DAS, the tallest plant (36.74 cm) was observed from the V_1A_1 treatment combination which was statistically similar to V_0A_0 and V_2A_0 (35.35 cm and 34.52 cm, respectively). On the other hand, the shortest plant (31.03 cm) was recorded from V_2A_2 treatment combination which was statistically similar to V_0A_2 (31.70 cm). At 60 DAS, the tallest plant (41.15 cm) was observed from the V_1A_1 treatment combination. On the other hand, the shortest plant (36.30 cm) was recorded from V_2A_2 treatment combination which was statistically similar to V_0A_1 and V_0A_2 (37.45 cm and 36.86 cm, respectively). At harvest, the tallest plant (66.98 cm) was observed from the V_0A_0 treatment combination, which was statistically similar to V_2A_0 (65.46 cm). On the other hand, the shortest plant (56.95 cm) was recorded from V_2A_1 treatment combination.

Table 1. Interaction effect of vermicompost and arsenic level on plant height of wheat at different data recording intervals

Interaction	**Plant height (cm) at**			
	30 DAS	**45 DAS**	**60 DAS**	**Harvest**
V_0A_0	28.25 bc	35.35 ab	39.59 b	66.98 a
V_0A_1	28.56 ab	33.60 c	37.45 cde	61.10 c
V_0A_2	27.17 de	31.70 d	36.86 de	61.13 c
V_1A_0	28.02 bcd	34.17 bc	38.11 cd	61.12 c
V_1A_1	29.29 a	36.74 a	41.15 a	62.78 bc
V_1A_2	27.54 cde	33.34 c	37.93 cd	60.31 c
V_2A_0	29.43 a	34.52 abc	39.72 b	65.46 ab
V_2A_1	26.90 e	33.49 c	38.25 c	56.95 d
V_2A_2	26.81 e	31.03 d	36.30 e	60.48 c
LSD $_{(0.05)}$	**0.989**	**1.525**	**1.310**	**3.292**
CV (%)	**7.44**	**9.51**	**7.19**	**11.22**

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability
V_0 = 0, V_1 = 2.5 t ha^{-1}and V_2 = 5.0, t ha^{-1} A_0= control (No Arsenic), A_1 = 25 mg As kg^{-1} soil, A_2 = 50 mg As kg^{-1} soil.

4.1.2 Number of tillers hill^{-1}

4.1.2.1 Effect of vermicompost

Number of tillers hill^{-1} of wheat showed significant variation due to effect of different levels of vermicompost at different data recording intervals (Figure 3). The maximum number of tillers hill^{-1} at 30 DAS (1.19) was recorded from the treatment V_2 (5.0 t ha^{-1}) while the maximum number of tillers hill^{-1} at 45 DAS (1.54) and 60 DAS (2.26) was obtained from the treatment V_1 (2.5 t ha^{-1}). On the other hand, the minimum number of tillers hill^{-1} at 30 DAS (1.08) and 45 DAS (1.46) was reported from the treatment V_0 (0 t ha^{-1}) while at 60 DAS, the minimum number of tillers hill^{-1} (2.20) was observed in treatment V_2 (5.0 t ha^{-1}).

The results of this study were in conformity with the findings of Patil and Bhilare (2006), Singh and Singh (2005) and Khandal and Nagendra (2002).

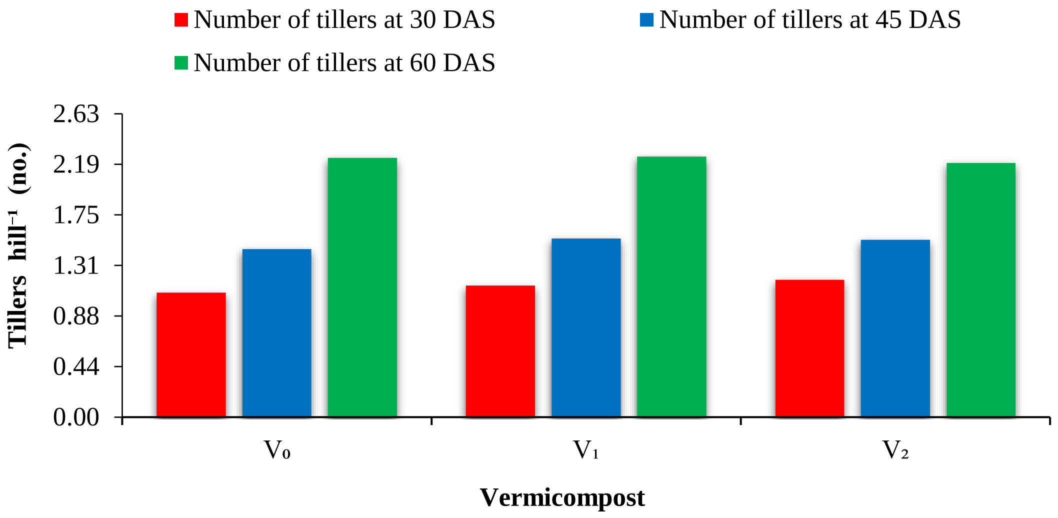

Figure 3. Effect of vermicompost on number of tillers hill^{-1} at different data recording intervals of wheat. (LSD$_{0.05}$ = 0.079, 0.122 and 0.119 at 30, 45 and 60 DAS, respectively).

V_0 = 0 t ha^{-1}, V_1 = 2.5 t ha^{-1}and V_2 = 5.0 t ha^{-1}

4.1.2.2 Effect of arsenic level

Different concentration of arsenic application exerted significant effect on number of tillers hill^{-1} of wheat (Figure 4). The maximum number of tillers hill^{-1} at 30 DAS (1.18) and 45 DAS (1.62) was recorded from control treatment (A_0) while at 60 DAS, the maximum number of tillers hill^{-1} (2.289) was obtained from the treatment A_1 (25 ppm). On the other hand, the minimum number of tillers hill^{-1} at 30 DAS (1.10) and 45 DAS (1.41) was reported from the treatment A_2 (50 ppm) while at 60 DAS, the minimum number of tillers hill^{-1} (2.20) was observed in treatment A_0 (0 ppm). Jahan (2016) and Ziasmin (2016) found similar kind of results regarding arsenic effect on number of tillers hill^{-1} of wheat.

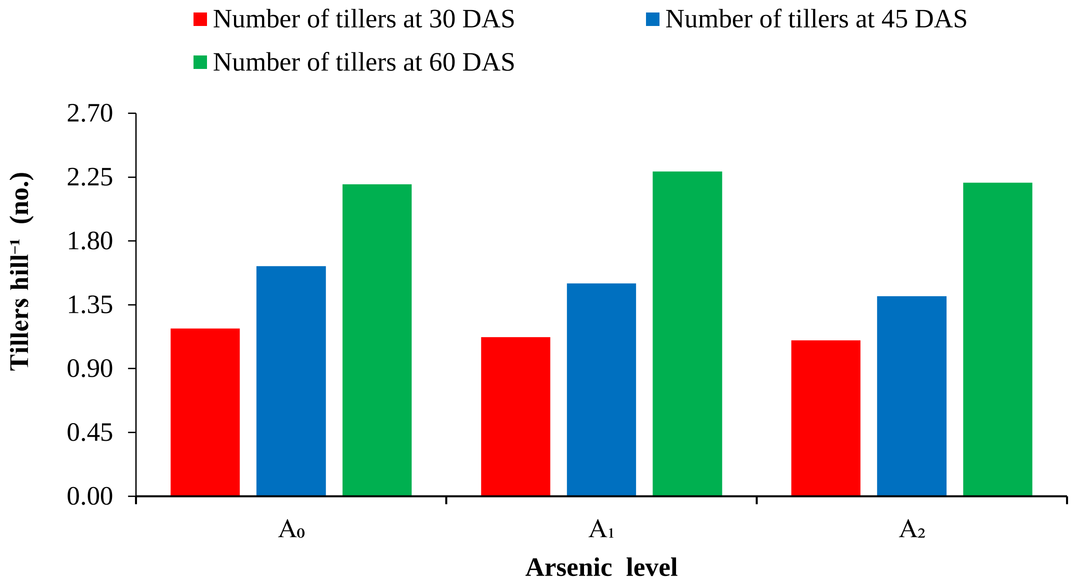

Figure 4: Effect of arsenic level on number of tillers hill^{-1} at different data recording intervals of wheat. (LSD $_{(0.05)}$ = 0.079, 0.122 and 0.119 at 30, 45 and 60 DAS; respectively).

A_0 =control (No Arsenic), A_1 = 25 mg As kg^{-1} soil and A_2 = 50 mg As kg^{-1} soil

4.1.2.3 Interaction effect of vermicompost and arsenic level

Interaction effect of different doses of vermicompost and different concentration of arsenic showed significant influence on number of tillers hill^{-1} of wheat at different data recording intervals (Table 2). At 30 DAS, the maximum number of tillers hill^{-1} (1.30) was observed from the V_2A_0 treatment combination while the minimum number of tillers hill^{-1} (1.07) was recorded from V_2A_2 treatment combination which was statistically similar to V_0A_0, V_0A_2, V_1A_0, V_1A_1 and V_1A_2 (1.13, 1.10, 1.12, 1.17 and 1.13, respectively). At 45 DAS, the maximum number of tillers hill^{-1} (1.77) was observed from the V_2A_0 treatment combination while the minimum number of tillers hill^{-1} (1.37) was recorded from V_2A_2 treatment combination which was statistically similar to V_0A_2 (1.33). At 60 DAS, the maximum number of tillers hill^{-1} (2.33) was observed from the V_2A_0 treatment combination which was statistically identical to V_1A_1 (2.33) and V_0A_1 (2.33) and statistically similar to treatment combination V_0A_2 (2.30) and V_1A_2 (2.27). On the other hand, the minimum number of tillers hill^{-1} (2.07) was recorded from V_2A_2 treatment combination which was statistically similar to V_0A_0 and V_1A_0 (2.10 and 2.17, respectively).

Table 2. Interaction effect of vermicompost and arsenic level on number of tillers hill^{-1} of wheat at different data recording intervals

Treatment combinations	**Number of tillers hill^{-1} at**		
	30 DAS	**45 DAS**	**60 DAS**
V_0A_0	1.13 bc	1.53 b	2.10 de
V_0A_1	1.00 d	1.50 b	2.33 a
V_0A_2	1.10 bc	1.33 c	2.30 ab
V_1A_0	1.12 bc	1.57 b	2.17 cde
V_1A_1	1.17 bc	1.53 b	2.33 a
V_1A_2	1.13 bc	1.53 b	2.27 abc
V_2A_0	1.30 a	1.77 a	2.33 a
V_2A_1	1.20 b	1.47 b	2.20 bcd
V_2A_2	1.07 c	1.37 c	2.07 e
LSD $_{(0.05)}$	**0.079**	**0.122**	**0.119**
CV (%)	**14.63**	**17.05**	**11.21**

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

V_0 = 0 t ha^{-1}, V_1 = 2.5 t ha^{-1}and V_2 = 5.0 t ha^{-1}, A_0 = control (No Arsenic), A_1 = 25 mg As kg^{-1} soil and A_2 = 50 mg As kg^{-1} soil

4.1.3 Root length

4.1.3.1 Effect of vermicompost

Length of root of wheat did not show any significant variation due to effect of different levels of vermicompost (Table 3). Numerically the longest root (8.53 cm) was recorded from the treatment V_0 (0 t ha^{-1}) while the shortest length of root (8.39 cm) was obtained from the treatment V_2 (5.0 t ha^{-1})

4.1.3.2 Effect of arsenic level

Different concentration of arsenic application exerted non-significant effect on root length of wheat (Table 3). Numerically the longest root (8.53 cm) was recorded from the treatment A_0 (0 ppm) while the shortest length of root (8.42

cm) was obtained from the treatment A_1 (25 ppm). This result was supported by the findings of Akhtar and Shoaib (2014), Zhang *et al.* (2009), Liu and Zhang (2007), Geng *et al.* (2006), Liu *et al.* (2005) and Karmakar *et al.* (2021) who mentioned that root length decreased with increasing level of arsenic.

4.1.3.3 Interaction effect of vermicompost and arsenic level

Interaction effect of different doses of vermicompost and different concentration of arsenic showed significant influence on root length of wheat (Table 3). The longest root of wheat (8.75 cm) was obtained from the treatment combination of V_1A_0, which was statistically similar to V_0A_0 (8.67 cm). On the other hand, the shortest root of wheat (8.165 cm) was reported from the treatment combination of V_2A_0 which was statistically similar to V_1A_1 (8.30 cm).

4.2 Yield Parameters

4.2.1 Spike length

4.2.1.1 Effect of vermicompost

Length of spike of wheat did not show any significant variation due to effect of different levels of vermicompost (Table 3). Numerically the longest spike (6.98 cm) was recorded from the treatment V_2 (5.0 t ha^{-1}) while the shortest length of spike (6.67 cm) was obtained from control treatment (V_0). Rai *et al.* (2017) mentioned similar kind of results from their research work.

4.2.1.2 Effect of arsenic level

Different concentration of arsenic application exerted significant effect on spike length of wheat (Table 3). The longest spike (7.38 cm) was recorded from the treatment A_0 (control) while the shortest length of spike (6.31 cm) was obtained from the treatment A_2 (50 mg As kg^{-1} soil). These results are in conformity with the findings of Jahan (2016) and Ziasmin (2016) who mentioned that spike length decreased with increasing level of arsenic concentration.

Table 3. Effect of vermicompost, arsenic level and their interaction on root length and spike length of wheat

Vermicompost	**Root length (cm)**	**Spike length (cm)**
V_0	8.527 ^{NS}	6.671 ^{NS}
V_1	8.501 ^{NS}	6.688 ^{NS}
V_2	8.388 ^{NS}	6.979 ^{NS}
Arsenic level		
A_0	8.528 ^{NS}	7.381 a
A_1	8.423 ^{NS}	6.648 b
A_2	8.466 ^{NS}	6.308 b
Interaction		
V_0A_0	8.67 ab	7.600 a
V_0A_1	8.477 abc	6.497 bc
V_0A_2	8.435 abc	5.915 d
V_1A_0	8.748 a	6.630 bc
V_1A_1	8.298 bc	6.965 b
V_1A_2	8.457 abc	6.468 c
V_2A_0	8.165 c	7.913 a
V_2A_1	8.493 abc	6.483 c
V_2A_2	8.505 abc	6.540 bc
LSD $_{(0.05)}$	**0.406**	**0.468**
CV (%)	**10.11**	**14.54**

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

NS = Non-significant, V_0 = 0 t ha^{-1}, V_1 = 2.5 t ha^{-1} and V_2 = 5.0 t ha^{-1} A_0 = control (No Arsenic), A_1 = 25 mg As kg^{-1} soil and A_2 = 50 mg As kg^{-1} soil

4.2.1.3 Interaction effect of vermicompost and arsenic level

Interaction effect of different doses of vermicompost and different concentration of arsenic showed significant influence on spike length of wheat (Table 3). The longest spike of wheat (7.91 cm) was obtained from the treatment combination of V_2A_0, which was statistically similar to V_0A_0 (7.60 cm). On the other hand, the shortest spike of wheat (5.92cm) was reported from the treatment combination of V_0A_2.

4.2.2 Grains spike^{-1}

4.2.2.1 Effect of vermicompost

Grains spike^{-1} (no.) of wheat showed significant variation due to effect of different levels of vermicompost (Table 4). The highest number of grains spike^{-1} (24.62) was recorded from control treatment (V_0) while the lowest number of grains spike^{-1} (23.82) was obtained from the treatment V_2 (5.0 t ha^{-1}). Rai *et al.* (2017), Dastmozd *et al.* (2015), Agrawal *et al.* (2003) mentioned similar kinds of findings in their study.

4.2.2.2 Effect of arsenic level

Different concentration of arsenic application exerted significant effect on number of grains spike^{-1} of wheat (Table 4). The highest number of grains spike^{-1} (24.49) was recorded from the treatment A_1 (25 mg As kg^{-1} soil), which was statistically similar to A_0 (24.42) while the lowest number of grains spike^{-1} (23.67) was obtained from the treatment A_2 (25 mg As kg^{-1} soil). These results were supported with the findings of Jahan (2016) and Ziasmin (2016).

4.2.2.3 Interaction effect of vermicompost and arsenic level

Interaction effect of different doses of vermicompost and different concentration of arsenic showed significant influence on number of grains spike^{-1} of wheat (Table 4). The maximum number of grains spike^{-1} of wheat (24.90) was obtained from the treatment combination of V_0A_1, which was statistically similar to V_0A_0 (24.83). On the other hand, the minimum number of grains spike^{-1} of wheat (23.43) was reported from the treatment combination of V_2A_2, which was statistically identical to V_1A_2 (23.43) and statistically similar to V_2A_1 (23.87).

Table 4. Effect of vermicompost, arsenic level and their interaction on number of grains spike^{-1}, spikelets plant^{-1} and 100-grain weight of wheat

Vermicompost	Grains spike^{-1} (no.)	Spikelets plant^{-1} (no.)	100-grain weight (g)
V_0	24.62 a	12.87 ^{NS}	2.65 a
V_1	24.13 a	12.53 ^{NS}	2.63 b
V_2	23.82 b	12.76 ^{NS}	2.69 a
Arsenic level			
A_0	24.42 a	13.40 a	2.82 a
A_1	24.49 a	12.52 b	2.72 b
A_2	23.67 b	12.23 b	2.43 c
Interaction			
V_0A_0	24.83 a	13.97 a	2.82 ab
V_0A_1	24.90 a	12.5 cd	2.71 cd
V_0A_2	24.13 c	12.13 d	2.43 f
V_1A_0	24.27 bc	12.97 b	2.84 a
V_1A_1	24.70 ab	12.50 cd	2.77 bc
V_1A_2	23.43 d	12.13 d	2.29 g
V_2A_0	24.17 bc	13.27 b	2.81 ab
V_2A_1	23.87 cd	12.57 c	2.69 d
V_2A_2	23.43 d	12.43 cd	2.59 e
LSD $_{(.05)}$	**0.520**	**0.385**	**0.057**
CV (%)	**4.53**	**6.37**	**4.51**

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

NS = Non-significant

V_0 = 0 t ha^{-1} V_1 = 2.5 t ha^{-1} and V_2 = 5.0 t ha^{-1}, A_0 =Control (No Arsenic), A_1 = 25 mg As kg^{-1} soil and A_2 = 50 mg As kg^{-1} soil

4.2.3 Spikelets plant^{-1}

4.2.3.1 Effect of vermicompost

Spikelets plant^{-1} (no.) of wheat showed non-significant variation due to effect of different levels of vermicompost (Table 4). Numerically the highest number of spikelets plant^{-1} (12.87) was recorded from control treatment (V_0) while the lowest number of spikelets plant^{-1} (12.53) was obtained from the treatment V_1 (2.5 t ha^{-1}). This result is in conformity with the findings of Agrawal *et al.* (2003).

4.2.3.2 Effect of arsenic level

Different concentration of arsenic application exerted significant effect on number of spikelets plant^{-1} of wheat (Table 4). The highest number of spikelets plant^{-1} (13.40) was recorded from the treatment A_0 (control) while the lowest number of spikelets plant^{-1} (12.23) was obtained from the treatment A_2 (50 mg As kg^{-1} soil) which was statistically similar (12.52) to A_1 (25 mg As kg^{-1} soil). Jahan (2016) and Ziasmin (2016) support the findings of this study.

4.2.3.3 Interaction effect of vermicompost and arsenic level

Interaction effect of different doses of vermicompost and different concentration of arsenic showed significant influence on number of spikelets plant^{-1} of wheat (Table 4). The maximum number of spikelets plant^{-1} of wheat (13.97) was obtained from the treatment combination of V_0A_0. On the other hand, the minimum number of spikelets plant^{-1} of wheat (12.13) was reported from the treatment combination of V_0A_2, which was statistically identical (12.13) to V_1A_2.

4.2.4 100-grain weight

4.2.4.1 Effect of vermicompost

Weight of 100-grain of wheat showed significant variation due to effect of different levels of vermicompost (Table 4). The highest weight of 100-grain (2.69 g) was recorded from the treatment V_2 (30 g pot^{-1}) which was statistically similar (2.65 g) to V_0 (control) while the lowest weight of 100-grains (2.63 g) was obtained from the treatment V_1 (2.5 t ha $^{-1}$) Dastmozd *et al.* (2015), Zhou and Chen (2011), Channabasanagowda *et al.* (2008) and Agrawal *et al.* (2003) also support the findings of this study.

4.2.4.2 Effect of arsenic level

Different concentration of arsenic application exerted significant effect on 100-grain weight of wheat (Table 4). The maximum weight of 100-grain (2.82 g) was recorded from the treatment A_0 (0 mg As kg^{-1} soil) while the minimum weight of 100-grain (2.43 g) was obtained from the treatment A_2 (50 mg As kg^{-1} soil). The results are in conformity with the findings of Karmakar and Prakash (2019), Jahan (2016), Ziasmin (2016) and Gulz *et al.* (2005) who mentioned that increasing levels of arsenic decreased test weight of wheat.

4.2.4.3 Interaction effect of vermicompost and arsenic level

Interaction effect of different doses of vermicompost and different concentration of arsenic showed significant influence on weight of 100-grains of wheat (Table 4). The highest weight of 100-grain of wheat (2.84 g) was obtained from the treatment combination of V_1A_0, which was statistically similar to that of V_0A_0 and V_2A_0 (2.82 g and 2.81 g, respectively). On the other hand, the lowest weight of 100-grain of wheat (2.29 g) was reported from the treatment combination of V_1A_2. The results are supported by the findings of Karmakar and Prakash (2019) who stated that vermicompost can mitigate the toxic effect of arsenic for increasing test weight of wheat.

4.3 Yield attributes of wheat

4.3.1 Grain yield plant^{-1}

4.3.1.1 Effect of vermicompost

Grain yield (g plant^{-1}) of wheat showed significant variation due to effect of different levels of vermicompost (Table 5). The highest grain yield (22.078 g plant^{-1}) was recorded from the treatment V_2 (5.0 t ha $^{-1}$) while the lowest grain yield (18.744 g plant^{-1}) was obtained from the treatment V_0 (0 t ha^{-1}). The result of this study was supported by the findings of Hadis *et al.* (2018), Rai *et al.* (2017), Dastmozd *et al.* (2015), Ibrahim *et al.* (2015), Yousefi and Sadeghi (2014) and Kizilkaya *et al.* (2012) who mentioned that vermicompost had significant effect in increasing grain yield of wheat.

4.3.1.2 Effect of arsenic level

Different concentration of arsenic application exerted significant effect on grain yield (g plant^{-1}) of wheat (Table 5). The maximum grain yield (24.38 g plant^{-1}) was recorded from the treatment A_0 (control) while the minimum grain yield (16.37 g plant^{-1}) was obtained from the treatment A_2 (50 mg As kg^{-1} soil). The results were in conformity with the findings of Jahan (2016), Ziasmin (2016), Zhang *et al.* (2009) and Liu *et al.* (2005) who mentioned that arsenic toxicity in soil reduced grain yield of wheat.

4.3.1.3 Interaction effect of vermicompost and arsenic level

Interaction effect of different doses of vermicompost and different concentration of arsenic showed significant influence on grain yield of wheat (Table 5). The highest grain yield of wheat (25.88 g plant^{-1}) was obtained from the treatment combination of V_1A_0. On the other hand, the lowest grain yield of wheat (13.68 g plant^{-1}) was reported from the treatment combination of V_1A_2, which was statistically similar (13.80 g plant^{-1}) to V_0A_2.

4.3.2 Straw yield plant^{-1}

4.3.2.1 Effect of vermicompost

Straw yield (g plant^{-1}) of wheat showed significant variation due to effect of different levels of vermicompost (Table 5). The highest straw yield (25.394 g plant^{-1}) was recorded from the treatment V_2 (5.0 t ha^{-1}) while the lowest straw yield (22.833 g plant^{-1}) was obtained from the treatment V_0 (0 t ha^{-1}). The result of this study was supported with the findings of Rai *et al.* (2017), Kizilkaya *et al.* (2012) and Bhuiyan (2005).

Table 5. Effect of vermicompost, arsenic level and their interaction on grain yield, straw yield, biological yield and harvest index of wheat

Vermicompost	**Grain yield (g plant^{-1})**	**Straw yield (g plant^{-1})**	**Biological yield (g plant^{-1})**	**Harvest index (%)**
V_0	18.744 c	22.833 c	41.578 c	44.604 b
V_1	21.183 b	24.072 b	45.256 b	46.424 a
V_2	22.078 a	25.394 a	47.472 a	46.616 a
Arsenic level				
A_0	24.38 a	27.38 a	51.756 a	47.17 a
A_1	21.26 b	23.83 b	45.094 b	47.17 a
A_2	16.37 c	21.09 c	37.456 c	43.30 b
Interaction				
V_0A_0	22.90 c	23.95 d	46.85 c	48.89 a
V_0A_1	19.53 e	23.58 d	43.117 d	45.39 d
V_0A_2	13.80 f	20.97 f	34.767 e	39.52 f
V_1A_0	25.88 a	28.47 b	54.35 a	47.65 bc
V_1A_1	23.98 b	25.70 c	49.68 b	48.41 ab
V_1A_2	13.68 f	18.05 g	31.73 f	43.21 e
V_2A_0	24.35 b	29.72 a	54.067 a	44.97 d
V_2A_1	20.27 e	22.22 e	42.483 d	47.72 abc
V_2A_2	21.62 d	24.25 d	45.867 c	47.16 c
LSD $_{(0.05)}$	**0.761**	**1.009**	**1.472**	**1.175**
CV (%)	**7.75**	**8.82**	**6.93**	**5.39**

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

V_0 = 0 t ha^{-1}, V_1 = 2.5 t ha^{-1} and V_2 = 5.0 t ha^{-1}, A_0 = control, A_1 = 25 mg As kg^{-1} soil and A_2 = 50 mg As kg^{-1} soil

4.3.2.2 Effect of arsenic level

Different concentration of arsenic application exerted significant effect on straw yield (g plant^{-1}) of wheat (Table 5). The maximum straw yield (27.38 g plant^{-1}) was recorded from the treatment A_0 (control) while the minimum straw yield (21.09 g plant^{-1}) was obtained from the treatment A_2 (50 mg As kg^{-1} soil).

4.3.2.3 Interaction effect of vermicompost and arsenic level

Interaction effect of different doses of vermicompost and different concentration of arsenic showed significant influence on straw yield of wheat (Table 5). The highest straw yield of wheat (29.72 g plant^{-1}) was obtained from the treatment combination of V_2A_0. On the other hand, the lowest straw yield of wheat (18.05 g plant^{-1}) was reported from the treatment combination of V_1A_2.

4.3.3 Biological yield plant^{-1}

4.3.3.1 Effect of vermicompost

Biological yield (g plant^{-1}) of wheat showed significant variation due to effect of different levels of vermicompost (Table 5). The highest biological yield (47.472 g plant^{-1}) was recorded from the treatment V_2 (5.0 t ha^{-1}) while the lowest biological yield (41.578 g plant^{-1}) was obtained from the treatment V_0 (0 t ha^{-1}). Singh and Singh (2005) and Ranwa and Singh (1999) supported the findings of this study.

4.3.3.2 Effect of arsenic level

Different concentration of arsenic application exerted significant effect on biological yield (g plant^{-1}) of wheat (Table 5). The maximum biological yield (54.756 g plant^{-1}) was recorded from the treatment A_0 (control) while the minimum biological yield (37.456 g plant^{-1}) was obtained from the treatment A_2 (50mg As kg^{-1} soil).

4.3.3.3 Interaction effect of vermicompost and arsenic level

Interaction effect of different doses of vermicompost and different concentration of arsenic showed significant influence on biological yield of wheat (Table 5). The highest biological yield of wheat (54.067 g plant^{-1}) was obtained from the treatment combination of V_2A_0, which was statistically similar (54.35 g plant^{-1})

to V_1A_0. On the other hand, the lowest biological yield of wheat (31.73 g plant^{-1}) was reported from the treatment combination of V_1A_2.

4.3.4 Harvest index

4.3.4.1 Effect of vermicompost

Harvest index (%) of wheat showed significant variation due to effect of different levels of vermicompost (Table 5). The highest harvest index (46.62%) was recorded from the treatment V_2 (5.0 t ha^{-1}) which was statistically similar (46.42%) to V_1 (2.5 t ha^{-1}) whereas the lowest harvest index (44.60%) was obtained from the treatment V_0 (0 t ha^{-1})**.** These results were supported by the findings of Dastmozd *et al.* (2015) and Agrawal *et al.* (2003) who mentioned that vermicompost application had significant effect in increasing harvest index of wheat.

4.3.4.2 Effect of arsenic level

Different concentration of arsenic application exerted significant effect on harvest index of wheat (Table 5). The maximum harvest index (47.17%) was recorded from the treatment A_0 (control) which was statistically identical (47.17%) to A_1 (25 mg As kg^{-1} soil). On the other hand, the minimum harvest index (43.30%) was obtained from the treatment A_2 (50 mg As kg^{-1} soil).

4.3.4.3 Interaction effect of vermicompost and arsenic level

Interaction effect of different doses of vermicompost and different concentration of arsenic showed significant influence on harvest index of wheat (Table 5). The highest harvest index of wheat (48.89%) was obtained from the treatment combination of V_0A_0, which was statistically similar to that of V_1A_1 and V_2A_1 (48.41% and 47.72%, respectively). On the other hand, the lowest harvest index of wheat (39.52%) was reported from the treatment combination of V_0A_2.

4.4 Functional relationships among different parameters

a) Relationship between the spike length and seed yield

Functional relationship analysis between spike length and seed yield revealed that, increase in spike length of wheat was positively correlated with corresponding increase in seed yield of wheat (Figure 5). The longer the length of wheat spike, the higher the possibility of more seed yield of wheat. The R-squared for the functional relationship model is 0.41, which means 41% of the variance in seed yield (plant $^{-1}$) can be explained by spike length (cm). The remaining 59% can be attributed to unknown, lurking variables or inherent variability.

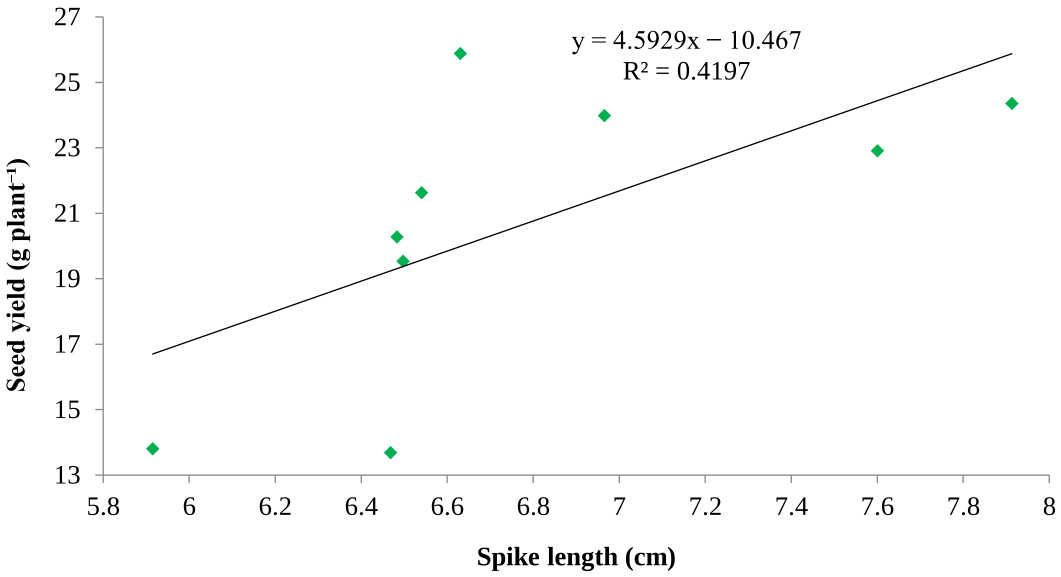

Figure 5. Functional relationship between the spike length and seed yield of wheat. R^2 calculated as 5% level of significance.

b) Relationship between the number of spikelets plant^{-1} and seed yield

Functional relationship analysis between the number of spikelets·plant^{-1} and seed yield revealed that, increase in number of spikelets·plant^{-1} of wheat was positively correlated with corresponding increase in seed yield of wheat (Figure 6). The higher the number of spikelets plant^{-1}, the higher the possibility of more seed yield of wheat. The R-squared for the functional relationship model is 0.42, which means 42% of the variance in the seed yield (g plant $^{-1}$) can be explained by spike length (cm). The remaining 58% can be attributed to unknown, lurking variables or inherent variability.

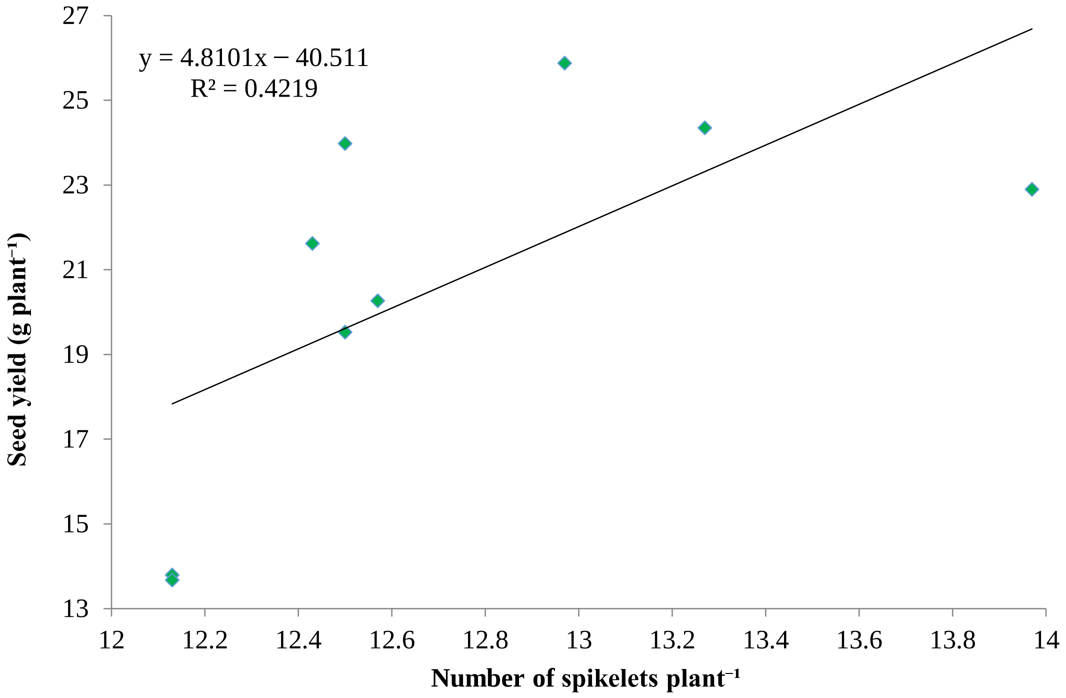

Figure 6. Functional relationship between the number of spikelets plant^{-1} and seed yield of wheat. R^2 calculated as 5% level of significance.

c) Relationship between the number of grains spike^{-1} and seed yield

Functional relationship analysis between the number of grains spike^{-1} and seed yield revealed that, increase in number of grains spike^{-1} of wheat was positively correlated with corresponding increase in seed yield of wheat (Figure 7). The higher the number of grains spike^{-1}, the higher the possibility of more seed yield of wheat. The R-squared for the functional relationship model is 0.16, which means 16% of the variance in the seed yield (g plant $^{-1}$) can be explained by number of spikelets plant $^{-1}$. The 84% can be attributed to unknown, lurking variables or inherent variability.

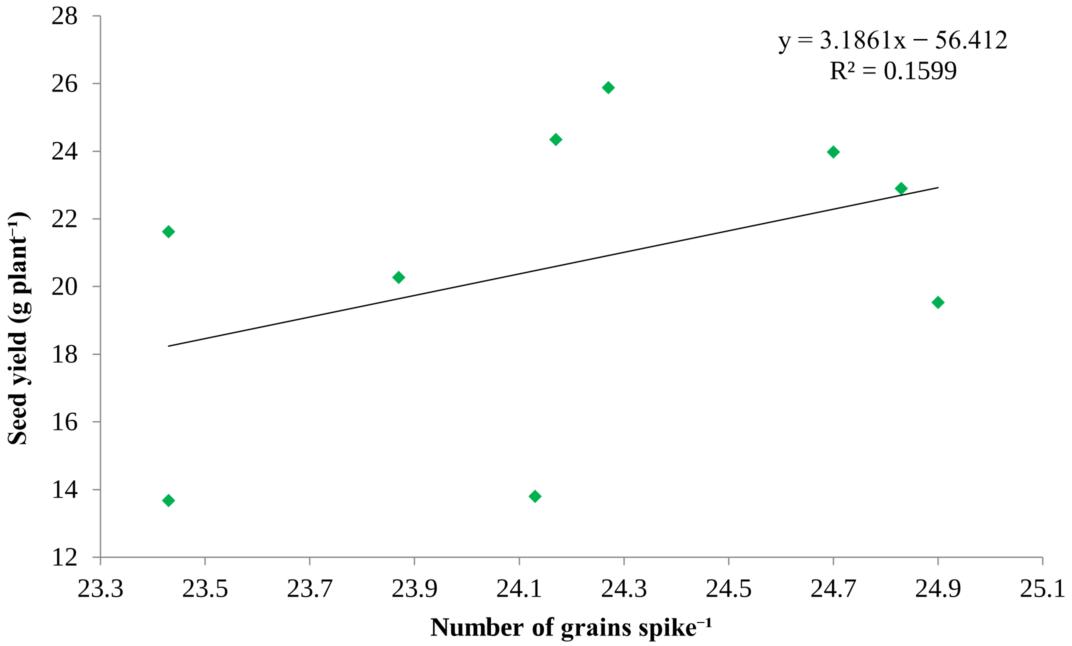

Figure 7. Functional relationship between the number of grains spike^{-1} and seed yield of wheat. R^2 calculated as 5% level of significance.

d) Relationship between the 100-grains weight and seed yield

Functional relationship analysis between weight of 100-grain and seed yield revealed that, increase in weight of 100-grain of wheat was strongly and positively correlated with corresponding increase in seed yield of wheat (Figure 8). The higher the weight of 100-grain of wheat, the higher the possibility of more seed yield of wheat. The R-squared for the functional relationship model is 0.86, which means 86% of the variance in the seed yield (g plant^{-1}) can be explained by the number of grains spike^{-1}. The remaining 14% can be attributed to unknown, lurking variables or inherent variability.

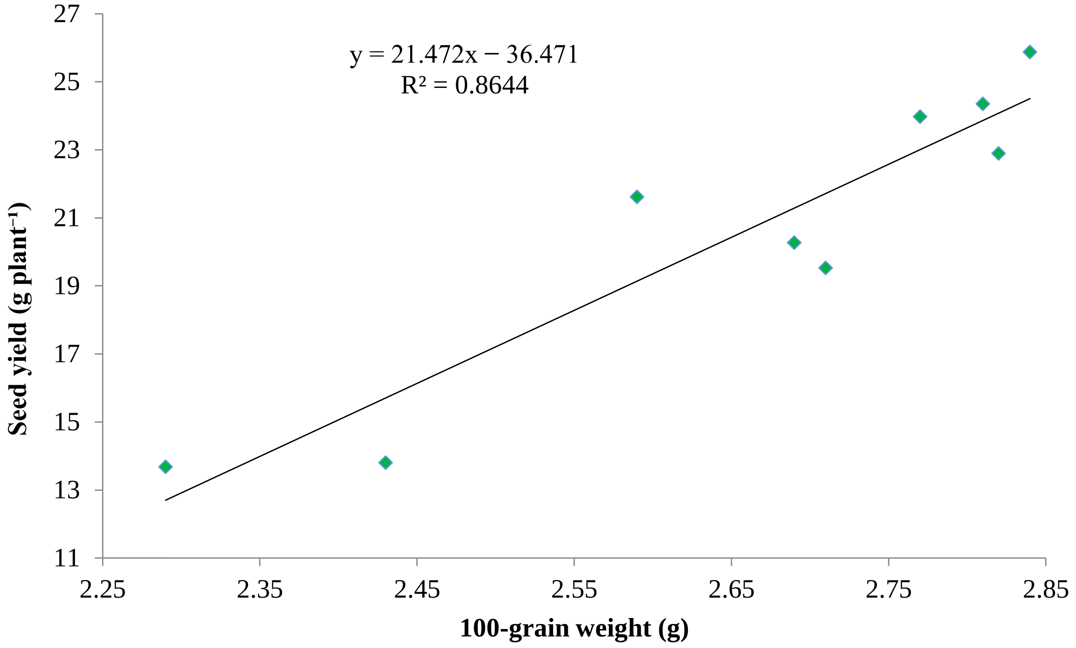

Figure 8. Relationship between the 100-grain weight and seed yield of wheat. R^2 calculated as 5% level of significance.

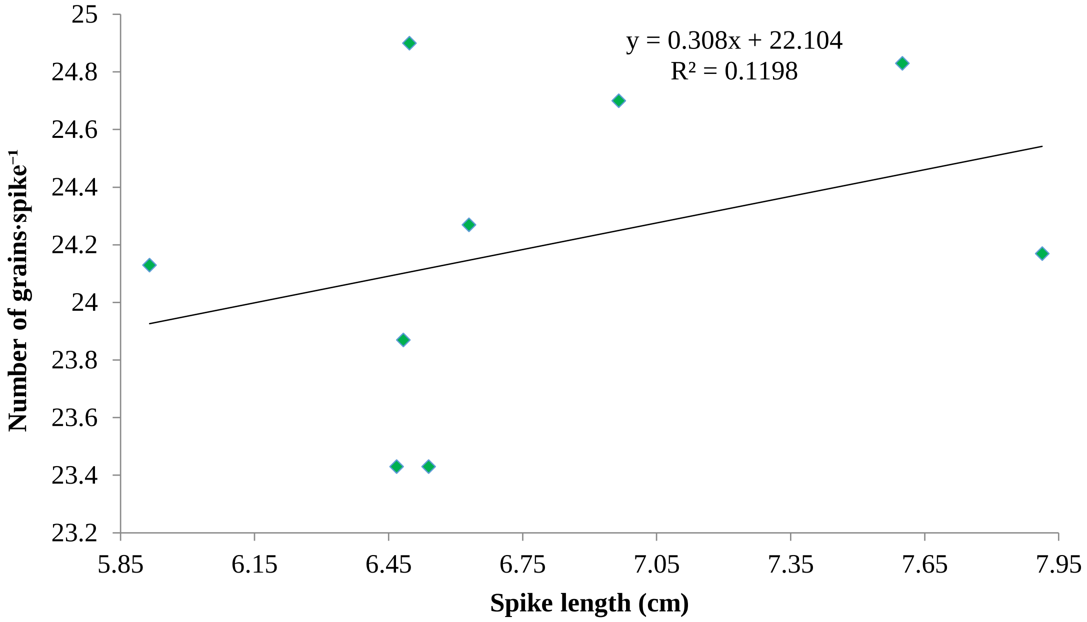

Figure 9. Functional relationship between the spike length and number of grain spike^{-1} of wheat. R^2 calculated as 5% level of significance.

e) Relationship between the spike length and number of grains spike^{-1}

Functional relationship analysis between spike length and number of grains spike^{-1} revealed that, increase in spike length of wheat was positively correlated with corresponding increase in number of grains spike^{-1} of wheat (Figure 9). The longer the length of wheat spike, the higher the possibility of more grains of wheat in the spike. The R-squared for the functional relationship model is 0.12, which means 12% of the variance in the grains spike^{-1} can be explained by grains length. The remaining 88% can be attributed to unknown, lurking variables or inherent variability.

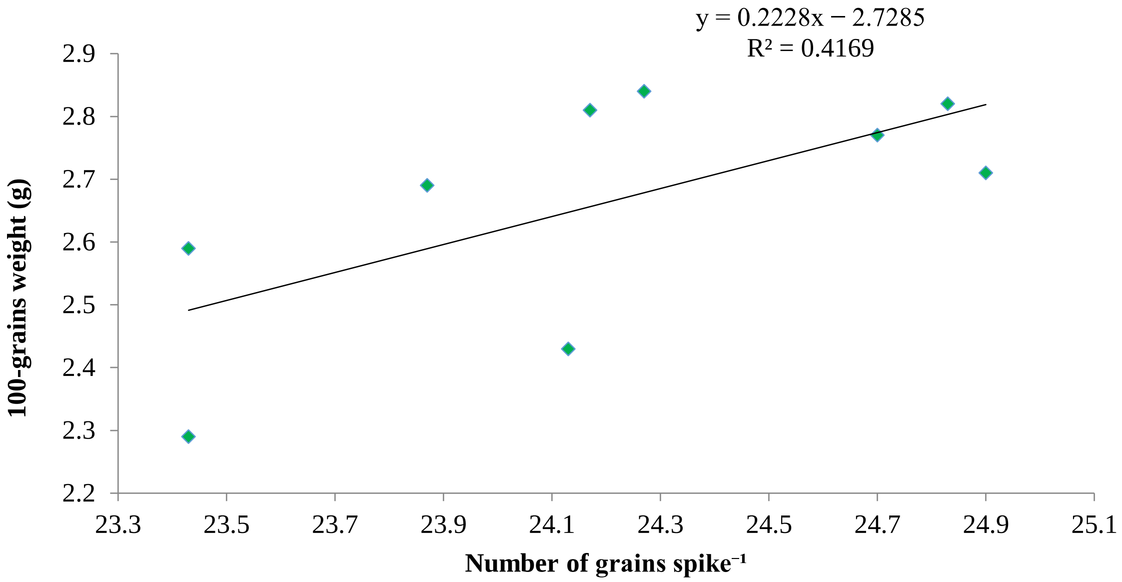

Figure 10. Functional Relationship between the number of grains spike^{-1} and 100-grain weight of wheat. R^2 calculated as 5% level of significance.

f) Relationship between the number of grains spike^{-1} and 100-grain weight (g)

Functional relationship analysis between the number of grains spike^{-1} and 100-grain weight (g) revealed that, increase in number of grains spike^{-1} of wheat was positively correlated with corresponding increase in weight of 100 grains of wheat (Figure 10). The higher the number of grains spike^{-1}, the heavier the number of grains spike of wheat. The R-squared for the functional relationship model is 0.42, which means 42% of the variance in the number of grains spike can be explained by the weight of 100 grain. The remaining 58% can be attributed to unknown, lurking variables or inherent variability.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the net house of the Department of Agronomy, Sher-e-Bangla Agricultural University during the period from November, 2019 to March, 2020 to investigate the effect of vermicompost on wheat at different arsenic level. The experiment comprised of two factors viz. Factor A: Arsenic concentrations (3), i. A_0: control (No Arsenic), ii. A_1: 25 mg As kg^{-1} soil and iii. A_2: 50 mg As kg^{-1} soil; Factor B: Vermicompost doses (3), i. V_0: 0 t ha^{-1}, ii. V_1: 2.50 t ha^{-1} and iii. V_2: 5.00 t ha^{-1}. This experiment was laid out in a randomized complete block design (RCBD) with six (6) replications. Data were collected on different aspects of growth, yield attributes and yield of wheat.

The results revealed that treatment V_2 (5.00 t ha^{-1}) exhibited its superiority compare with that of other vermicompost treatments V_0 and V_1 in terms of seed yield. Treatment V_2 out-yielded over V_1 (2.50 t ha^{-1}) by 4.22% higher yield. Treatment V_2 also showed the highest weight of 100-grain (2.693 g), maximum length of wheat spike (6.979 cm), highest straw yield (25.394 g $plant^{-1}$), highest biological yield (47.472 g $plant^{-1}$) and the harvest index (46.616%) than other treatments in this experiment. On the other hand, the treatment V_0 (o t ha^{-1}) returned with 17.78% lower yield than treatment V_2 95.00 t ha^{-1}) which was significantly the lowest compare with other treatments under study.

Significant differences existed among different level of arsenic concentration with respect to yield and yield attributing parameters of wheat. A yield advantages of 3.12 g $plant^{-1}$ (14.67%) and 8.01 g m^{-2} (48.93%) over A_1 (25 mg As kg^{-1} soil) and A_2 (50 mg As kg^{-1} soil) treated plot, respectively was found, which was possibly aided by higher plant height at harvest (64.52 cm), longer root length (8.528 cm), longer spike length of wheat (7.381 cm), higher number of grains $spike^{-1}$ (24.42), higher number of spikelets $plant^{-1}$ (13.40), higher weight of 100-grain (2.82 g), straw yield (27.38 g $plant^{-1}$), biological yield

(51.756 g plant^{-1}) and harvest index (47.17%) in the A_0 (0 mg As kg^{-1} soil or no arsenic) treatment. On the other hand, between the two arsenic concentrations, A_1 treated pots performed better than A_2 treated pots regarding the growth, yield attributing and yield parameters.

Interaction results of vermicompost doses and arsenic concentrations indicated that all the studied parameters were influenced significantly. The highest grain yield (25.88 g plant^{-1}) was found in V_1A_0 (2.5 t ha^{-1} vermicompost × No arsenic) interaction due to the longest length of root (8.748 cm) and the highest weight of 100-grain (2.84 g) production with significantly the highest amount of biological yield (54.35 g plant^{-1}). Among the treatment combinations where arsenic was applied, V_1A_1 combination (15 g pot^{-1} vermicompost × 25 mg As kg^{-1} soil arsenic) showed the highest grain weight (23.98 g plant^{-1}) aided by taller plant at harvest (62.78 cm), higher number of tillers hill^{-1} (2.33), longer length of spike (6.965 cm), higher number of grains spike^{-1} (24.70), heavier weight of 100-grain (2.77 g), higher biological weight (49.68 g plant^{-1}) and higher harvest index (48.41%).

There were positive relationships observed between seed yield of wheat and spike length, number of spikelets plant^{-1}, number of grains spike^{-1} and 100-grain weight. 100-grain weight showed strong positive relationship with seed yield. Number of grains spike^{-1} with 100-grain weight and spike length with number of grains spike^{-1} also showed functional positive relationship.

Conclusion

From the above result it was revealed that V_2 (5.00 t ha^{-1}) and A_0 (control or no arsenic) treatment gave higher yield along with higher values in most of the yield attribute parameters. Among the vermicompost treatments, 5.00 t ha^{-1} was high yielder than 2.50 t ha^{-1} treatments. Among the interactions, V_1A_0 and V_2A_0 were superior in most of the growth and yield attributing parameters along with grain yield. Interaction of V_1A_0 (2.50 t ha^{-1} vermicompost × No arsenic) performed the best in respect of yield attributing and yield parameters including grain yield. Among the treatment combinations where arsenic was applied, V_1A_1 and V_2A_2 combination showed better performance compare to other combination. It can be said that higher amount of vermicompost is required for combating higher concentration of arsenic in soil solution. From the result of the experiment, it may be concluded that the effect of vermicompost depends on the levels of Arsenic. Vermicompost @ 2.50 t ha^{-1} seems promising for combating 25 mg As kg^{-1} soil arsenic in wheat field and at the same time 50 mg As kg^{-1} soil arsenic can be combated by the application of 5.0 t ha^{-1} of vermicompost.

Recommendation

Considering the results of the present experiment, further studies in the following areas are suggested:

- Different doses of organic fertilizers including vermicompost may be used with different concentration of arsenic for getting wider range of fertilizer recommendation for combating arsenic problem.
- Studies of similar nature could be carried out in different agro-ecological zones (AEZ) of Bangladesh for the evaluation of zonal adaptability.

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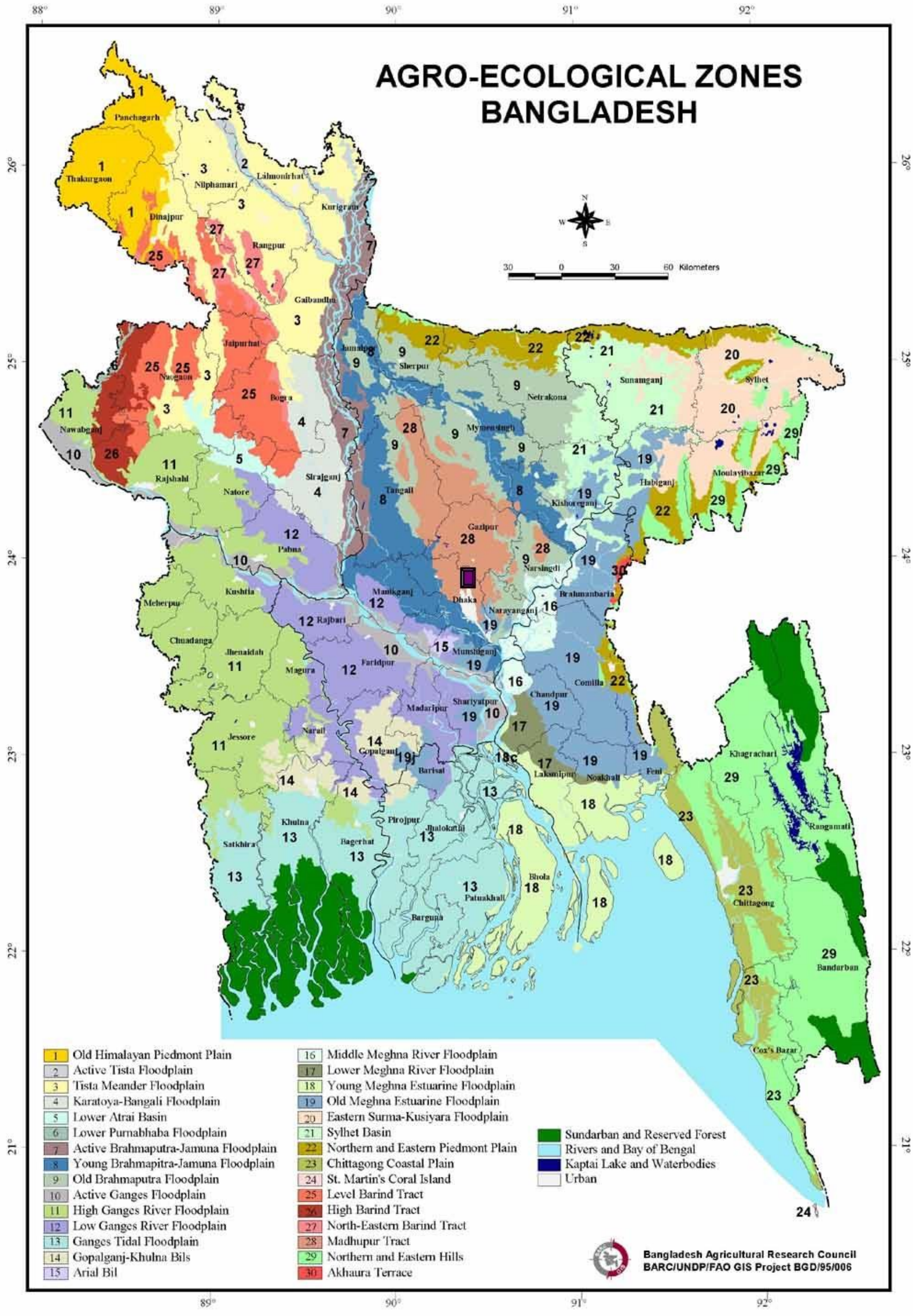
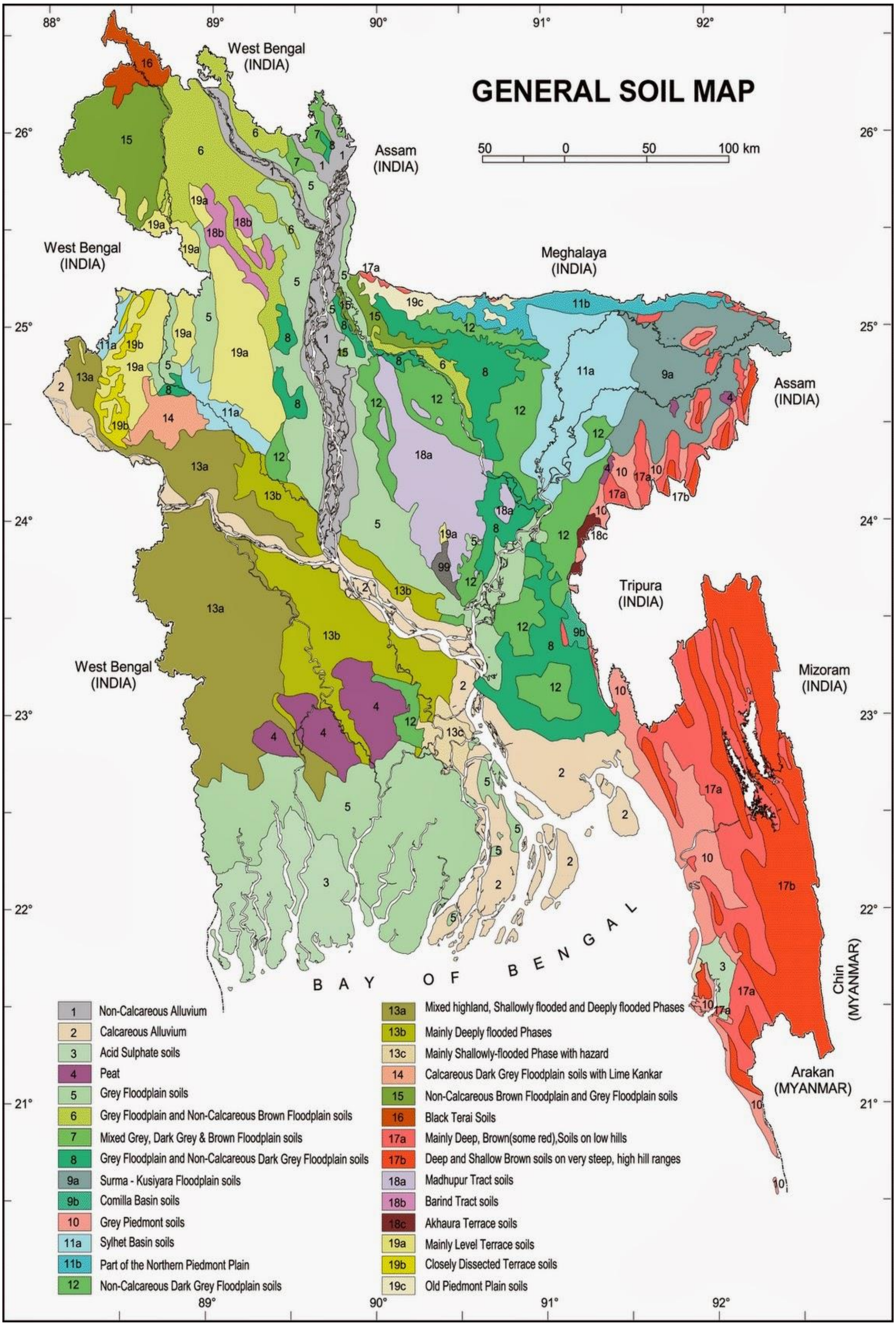
APPENDICES

Appendix I (A): Map showing the experimental sites under study



🟪 **The experimental site under study**

Appendix I (B): Map showing the general soil sites under study



Appendix II. Characteristics of soil of experimental site is analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Experimental field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	27
% Silt	43
% clay	30
Textural class	Silty-clay
pH	5.5
Organic carbon (%)	0.43
Organic matter (%)	0.75
Total N (%)	0.075
Available P (ppm)	21.00
Exchangeable K (meq/ 100 g soil)	0.11
Available S (ppm)	43

Source: SRDI, 2019

Appendix III. Monthly average of temperature, relative humidity, total rainfall and sunshine hour of the experimental site during the period from November 2019 to March 2020

Year	Month	Temperature			Relative Humidity (%)	Rainfall (mm)	Sunshine (Hour)
		Max (°C)	Min (°C)	Mean (°C)			
2019	**November**	32	24	29	65	42.8	349
	December	27	19	24	53	1.4	372
2020	**January**	27	18	23	50	3.9	364
	February	30	19	26	38	3.1	340
	March	35	24	31	38	19.6	353

Appendix IV. Analysis of variance (mean square) of plant height of wheat as influenced by vermicompost, arsenic level and their interaction

Source of variation	Degrees of freedom	Mean Square value of			
		Plant height at 30 DAS	Plant height at 45 DAS	Plant height at 60 DAS	Plant height at harvest
Vermicompost	2	1.454*	14.235*	6.508*	22.240*
Arsenic	2	9.661*	41.269*	24.497*	99.545*
Vermicompost × Arsenic	4	5.879*	8.429*	12.563*	44.156*
Error	45	4.337	10.318	7.612	48.075
Total	53	4.545	11.491	8.581	48.747

* indicates significant at 5% level of probability

Appendix V. Analysis of variance (mean square) of tiller no. of wheat as influenced by vermicompost, arsenic level and their interaction

Source of variation	Degrees of freedom	Mean Square value of		
		Tiller no. at 30 DAS	Tiller no. at 45 DAS	Tiller no. at 60 DAS
Vermicompost	2	0.0557*	0.0422*	0.0156*
Arsenic	2	0.0335*	0.2022*	0.0422*
Vermicompost × Arsenic	4	0.0407*	0.0644*	0.1011*
Error	45	0.0276	0.0664	0.0627
Total	53	0.0299	0.0704	0.0630

* indicates significant at 5% level of probability

Appendix VI. Analysis of variance (mean square) of root length of wheat as influenced by vermicompost, arsenic level and their interaction

Source of variation	Degrees of freedom	Mean Square value of
		Root length
Vermicompost	2	0.0989 ^{NS}
Arsenic	2	0.0502 ^{NS}
Vermicompost × Arsenic	4	0.2902*
Error	45	0.7331
Total	53	0.6500

* indicates significant at 5% level of probability
NS = Non-significant

Appendix VII: Analysis of variance (mean square) of yield contributing characters of wheat as influenced by vermicompost, arsenic level and their interaction

Source of variation	Degrees of freedom	Mean Square value of			
		Number of grains per spike	Number of spikelets per plant	Spike length	Weight of 100-grain
Vermicompost	2	2.927*	0.519 NS	0.540 NS	0.019*
Arsenic	2	3.754*	6.645*	5.415*	0.736*
Vermicompost × Arsenic	4	0.315*	0.625*	1.650*	0.064*
Error	45	1.199	0.656	0.972	0.014
Total	53	1.294	0.875	1.174	0.046

* indicates significant at 5% level of probability
NS = Non-significant

Appendix VIII. Analysis of variance (mean square) of yield characters of wheat as influenced by vermicompost, arsenic level and their interaction

Source of variation	Degrees of freedom	Mean Square value of			
		Grain yield per hill	Straw yield per hill	Biological yield per hill	Harvest index
Vermicompost	2	53.578*	29.527*	159.552*	22.203*
Arsenic	2	293.541*	178.936*	921.639*	90.126*
Vermicompost × Arsenic	4	58.991*	50.949*	188.191*	52.277*
Error	45	2.567	4.516	9.618	6.126
Total	53	19.731	15.546	63.169	13.386

* indicates significant at 5% level of probability