EFFECT OF GLYPHOSATE HERBICIDE ON PHOSPHORUS AVAILABILITY AND SUBSEQUENT GROWTH AND YIELD OF WHEAT

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CERTIFICATE

*This is to certify that the thesis entitled **"EFFECT OF GLYPHOSATE HERBICIDE ON PHOSPHORUS AVAILABILITY AND SUBSEQUENT GROWTH AND YIELD OF WHEAT"** submitted to the Department of Agricultural Chemistry, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka-1207, in partial fulfillment of the requirements for the degree of MASTERS OF SCIENCE in AGRICULTURAL CHEMISTRY, embodies the result of a piece of bona fide research work carried out by **NILUFA AKTER JEANY,** bearing Registration No. **14-06206** 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 been duly acknowledged.

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Dedicated to…

My beloved
Parents and the
farmers who feed
the nation

LIST OF ABBREVIATIONS

AEZ	Agro-Ecological Zone
ANOVA	Analysis of Variance
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BBS	Bangladesh Bureau of Statistics
Cm	Centimeter
CV	Co-efficient of variance
^{0}C	Degree Centigrade
df	Degree of Freedom
DAS	Days After Sowing
Etc	*et cetera* (and so on)
FAO	Food and Agriculture Organization
FMPE	Farm Machinery and Post-harvest Process Engineering
G	Gram
HG	High Glyphosate
MBC	Microbial Carbon
MBN	Microbial Nitrogen
Min P	Minimum Phosphorus
NG	No Glyphosate
NS	Not Significant
RG	Recommended Glyphosate
P	Phosphorus
PBP	Plant Back Period
PEPC	Phosphoenolpyruvate Carboxylase
SE	Standard Error
SOM	Soil Organic Matter
TSP	Tripple Super Phosphate
WRC	Wheat Research Centre

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The Author

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

EFFECT OF GLYPHOSATE HERBICIDE ON PHOSPHORUS AVAILABILITY AND SUBSEQUENT GROWTH AND YIELD OF WHEAT

ABSTRACT

A field experiment was conducted in Grey Terrace soils under Madhupur Tract Agro-Ecological Zone (AEZ-28) during 2019-2020 to observe the effect of glyphosate on wheat growth applied before crop establishment to the soil. The experiment was tested by applying glyphosate 2 and 7 days before land preparation. The soils under two different phosphorus doses (minimum phosphorus and high dose of phosphorus) and three glyphosate doses (no glyphosate, recommended dose of glyphosate and high dose of glyphosate). Twelve treatments were studied in split-split plot design with three replications. The growth and yield parameters of wheat, weed biomass and P concentration were varied due to the plant back period, glyphosate and phosphorus doses applied to the soil before crop establishment. When glyphosate applied 2 days before, emergence, germination and plant growth were hampered in compared to 7 days before application. Application of high glyphosate dose with high P significantly reduce yield and yield contributing characters of wheat crops. The phosphorus concentration in clay loam soil was also the highest recorded in the high glyphosate combined with high P dose. When glyphosate was applied at the recommended dose 7 days before land preparation, the yield and yield contributing characters were not hampered compared with high dose of glyphosate. The key result from the experiment was the interaction of plant back period and high rate of glyphosate with high dose of P fertilizer, leading to a negative effect on wheat phenotypic and yield characters in clay loam soil. The interaction of recommended dose of glyphosate and phosphorus reduce the weed biomass and increase the phosphorus availability in clay loam soil, and thus reducing the total cost of production for wheat. However, most of the effects were observed at the initial stage of crop growth.

CHAPTER I

INTRODUCTION

INTRODUCTION

Wheat (*Triticum aestivum* L.) primarily grows across the diverse range of environments (WRC, 2009). The largest area of wheat cultivation in the warmer climates exists in the South-East Asia including Bangladesh, India and Nepal (Dubin and Ginkel, 1991). Importance of wheat crop may be understood from the fact that it covers about 42% of total cropped area in rice-wheat system in South Asia (Iqbal et al., 2002). It contributes to the national economy by reducing the volume of import of cereals for fulfilling the food requirements of the country (Razzaque et al., 1992).

In Bangladesh, wheat is the second most important cereal crop (BBS, 2020). Domestic wheat production rose to more than 1 million tons per year, but was still only 7-9% of total food grain production (BARI, 2010). In 2020, wheat production for Bangladesh was 1,180 thousand tons. Between 1999 and 2020, wheat production in Bangladesh was decreasing on average by 0.44% each year, although before that, it grew from 111 thousand tons in 1973 to 1,988 thousand tons in 1999 (BBS, 2020). Generally, wheat supplies carbohydrate (69.60%), protein (12%), fat (1.72%), minerals (16.20%) and also other necessary nutrients in trace amount (BARI, 1997).

Yield of wheat is very low in Bangladesh. However, the low yield of wheat is not an indication of low yielding potentiality of this crop, but may be attributed to a number of reasons viz. unavailability of quality seeds of high yielding varieties, delayed sowing after the harvest of transplanted aman rice, short winter season, fertilizer management, weed, disease and insect infestation and improper or limited irrigation facilities (Radmehr et al., 2003). Major constraints to wheat grain yield in this region are inadequate rainfall and high temperatures during grain filling at the end of the growing season (Andarzian et al., 2008).

Weed infestation is one of the destructive integral pests in upland crop like wheat. Weeds are the nutrient absorbing competitive plants which grow out of place spontaneously even under adverse condition. It is often said that crop production is a fight against weeds (Cardina et al., 2002; Mohler et al., 2006). The edaphic and climatic condition of Bangladesh favors the growth of weed. High competitive ability of weeds exerts a serious negative effect on crop production causing significant losses in crop yield (Mishra et al., 2005). Many scientists from South Asia reported weed as the major constraint to wheat cultivation (Qureshi and Bhatti, 2001; Singh et al., 2003). It is reported that weeds reduced wheat yield up to 25-30% in Pakistan (Nayyar et al., 1994) 20-40% in India (Mishra, 1997) and up to 50% in Nepal (Ranjit, 2002). It has been reported that most of the plant parameters of wheat are affected by weed competition (Karim and Mamun, 1988). Karim (1987) estimated that weeds caused a loss of 33% of total yield in Bangladesh, where most of the plant parameters including plant height, number of tillers, number of panicles, grain weight etc. are affected by weed competition. Agricultural labour shortage during winter season is a new phenomenon in Bangladesh that hampers the timely crop production in Bangladesh. Weed management also suffers from labour shortage (Islam, 2018). Accordingly, farmers rely heavily on herbicide for weed eradication.

Glyphosate is the most widely used herbicide in crop production. Glyphosate inhibits the 5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS) enzyme found in the shikimic acid pathway. The inhibition of EPSPS leads to reduced feedback in the inhibition pathway, which results in the accumulation of shikimate-3-phosphate, which is converted to shikimate or shikimic acid (Zulet-González et al., 2020). Glyphosate is considered as a non-selective, broad spectrum herbicide, because the EPSPS enzyme in higher plants is inhibited by glyphosate. Many researchers assume that the deficiency of aromatic amino acid production in glyphosate treated plants leads to plant destruction. However, there are indications that the deregulation of the shikimic acid pathway is the cause for plant mortality, where increased carbon flow to shikimate-3-phosphate causes shortages in the carbon required for other essential pathways. For example, studies conducted on sugar beet demonstrate that the deregulation of the shikimic acid pathway results in a reduced rate of ribulose bisphosphate carboxylase regeneration, photosynthesis and starch synthesis (Yanniccari et al., 2017). Despite favorable evaluations of weed control efficacy and environmental risks of glyphosate, an increasing number of more recent observations suggest a relationship between extensive glyphosate application and adverse nontarget effects in agroecosystems. The more significant among these concerns are: (1) persistence in the environment, (2) effects on crop health, and (3) interaction with crop nutrition (Yamada et al., 2009).

The adverse effects depend on the plant back period of glyphosate depends on soil chemical properties such as pH, texture and nutritional status and doses of glyphosate (Tesfamariam et al., 2009). The applied glyphosate or residual glyphosate may be completely locked up with clay in soil but where there is higher available phosphate in soil this can increase glyphosate availability. Residual glyphosate may affect soil microorganisms, causes non-target injury, lock-up soil nutrients and promote diseases in plants. High doses of glyphosate for the subsequent crops may result in much more severe and more enduring crop damage, while lower doses can cause economic loss without desirable action on the weeds. Glyphosate effects on wheat growth are not widely reported, and phytotoxic doses for all soil types are not known. The mechanisms and factors that influence glyphosate effects in soil are poorly understood. The implications of glyphosate reactions with minerals and the residual effect of glyphosate on subsequent growth of wheat need to be more thoroughly assessed (Kanissery et al., 2019).

Phosphorus is the second major plant nutrient. It plays a vital role in several physiological processes viz photosynthesis, respiration, energy storage and cell division/enlargement. The mechanism of binding of glyphosate and phosphate compounds to the soil solids and adsorption sites have been found to be similar (Gimsing and Borggaard, 2002). Thus, the mobility of P in the soil is affected by the presence of glyphosate. The interaction between glyphosate and P in soil was reported shortly after the herbicide was launched into the market (Newton et al. 1994). Many of the studies conducted later have verified that P and glyphosate compete for adsorption in the soil, and the competition substantially differs in various kinds of soils (Eker et al., 2006; Hance 1976; Wang et al., 2004). Therefore, the competition between glyphosate and P for adsorption sites in soil seems to be vital and makes a significant impact on mobility and crop availability aspects of P as a crop nutrient. Unfortunately, there is sparse information in the literature that demonstrates the noteworthy effect of such competition on P nutrition of crops, and thus further investigation is required. The research work aims to describe the consequences of glyphosate applied at higher doses on wheat growth when either combined or not with abundant or higher available P. Based on above discussion following objectives were taken for this study-

- To find out the effects of glyphosate application on growth characters, yield and weed biomass of wheat.
- To determine the safe period of pre-sowing glyphosate application for wheat crop establishment.
- To assess the influence of glyphosate application on phosphorus availability in soil.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Weed is the integral part of crops. It reduces wheat yield. Selection of and application of herbicides is an important investigation to suppress weed growth and thus give the best performance with regard to quantity and quality of wheat. In Bangladesh, research work related to weed management through application of glyphosate are scarce. To justify the present study attempts have been made to incorporate some of the important findings of renowned scientists and research work in this country and in other countries have been reviewed under the following headings:

2.1 Weed vegetation in wheat

The weed vegetation of a particular area is determined not only by the environment but also by biological factors. Weed vegetation in crops field is the result of cropping system, cropping season, topography of land and management practices like time and degree of land preparation, type of cultivar, time of planting, planting rate, fertilizer management, weeding method and intensities and so on practiced by the farmers at different times during the crop cycle.

Rahman (1974) observed that the infesting species of weed in wheat crop were *Chenopodium album, Cynodon dactylon, Eleusine indica, Cyperus rotundus* and a few legume species. *Chenopodium album* constituted 56.5% of the total weed vegetation and he also observed a wider range of weed flora in wheat crop which included *Chenopodium album, Paspalum distichum, Gnaphalium luteo-album, Vicia sativa, Dactyloctenium aegyptium, Cyperus rotundus, Hydrocotyle asiatica, Marsilea quadrifolia* and *Eclipta prostrata. Chenopodium album* ranked top the list in respect of intensity of infestation.

Jalis (1987) studied the predominating influence of *Phalaris minor* and *Avena fauta* in wheat. Nesterove and Chukanova (1981) recorded the deduction in grain yield of wheat caused by different populations of weeds and greatest reduction was found by the presence of *Convolvulus arvensis* and *Amaranthus retrotlexus*. Sahu (1981) observed that, the prominent infesting species of weeds in wheat crop were *Chenopodium album, Digitaria sanguinalis, Eragrastic diarrhna, Lathyrus sativus* and *Medicago denticulata.*

Mamun et al. (1986) observed that wheat fields were infested with 16 species of weeds including *Avena fatua, Phalaris minor, Lolium temulenturn* and *Cynodon dactylon.* As per Roder et al. (1982) the main weeds of wheat field in the Dresden area of German Democratic Republic were *Apera spiceventi, Lolium anplexicanle, Lolium purpuream, Cynodon dactylon, Cyperus rotundus, Matriecaria chamomillia, Setaria medico, Veromica henderofolia, Viola arvensis, Lipia nudiflora, Melilotus indica, Launca pinnatifida, Cannabis sativa, Nicotina plumbginifolia, Spergula arvensis, Phalaris minor.*

Gaffer (1987) observed that the prominent infesting species of weeds in wheat crop were *Bonnaya brachiata, Chenopodium album, Vicia hirsuta, G. luteoalbum, Cynodon dactylon, Cyperus rotundus, Solanum nigram, Physalis heterophylla* and *Amaranthus viridis*. Among the infesting species of weeds *Chenopodium album* and *Cyperus rotundus* recorded the first and second position in respect of intensity of infestation.

Islam (1987) noticed that weed flora in a wheat crop were five grass species *Digitaria aegyptium, Echinochloa crussgalli, Cynodon dactylon, Parapholis incurva* and *Leersia hexandra,* seven broadleaf species *Chenopodium album, Vicia sativa, Amaranthus viridis, Physalis heterophylla, Solanum torvum, E. prastrata and Gnaphalium luteo-album,* one sedge, *Cyperus rotundus* and a few other species of weeds. The cumulative relative density of the broadleaf weeds was 70.81% against 22.37% of the grass weeds and 6.8% of the sedge.

Among the infesting species, *Chenopodium album* was the principal weed having about 57.05% of the total weed vegetation followed by the grass weed, *Dactyloctenium aegyptium*, the sedge, *Cyperus rotundus* and the broadleaf weed, *Vicia sativa*. Similar vegetation of weed association has also been reported by Khan et al. (1980) in wheat field at the same location.

Mamun and Salim (1989) reported that, eight weed species infested wheat crop at the Bangladesh Agricultural University Farm. Among them the heirerchical positions of five most dominant species were *Chenopodium album*, *Vicia sativa*, *Cynodon dactylon*, *Cyperus rotundus* and *Parapholis incurva*.

From a weed survey conducted by Ahmed (1993) revealed that 51 weed species were present in wheat fields at Riwat area in Pakistan, where 84% were dicotyledonous and nearly 79% were annuals. On the basis of an index of importance 5 most dominant species were *Convolvulus arvensis, Anagallis arvensis, Fumaria indica, Oxalis corniculata* and *Taraxacum officinale*.

Hosmani (1995) observed that the common weeds observed in wheat in Karnataka include *Dinebra retrotlexa, Brachiaria isachne, Chrozophora rotteri, Portulaca spp., Trianthama portulacastrum, Amaranthus spp. Parthenium hysterophorus* and *Digera arvensis.* Kushwaha and Singh (2000) reported infestation of wheat with *Cinnivera dinnatifida, Phalaris minor, Cyperus rotundus, Cynodon dactylon, Anagallis arvensis, Chenopodium album, Fumaria parviflora, Portulaca oleracea, Avena fatua, Mililotus indica* and *Panicum spp. at* Haridwar, Uttar Pradesh.

Tiwari and Parihar (1993) and Malik et al. (1995) observed *Chenopodium album, Meilotus indica* and *Vicia sativa* as major weed flora in wheat field at Hissar and Sarkanda, Bilaspur (Madhya Pradesh).
Qureshi and Bhatti (2001) showed that upto 45 weeds species have been reported in wheat field in different wheat-growing areas in Pakistan. *Phalaris*

minor Rumex dentatus, Coronopus didymus, Medicago denticulata, *Chenopodium album*, and *Poa annua* have been reported as the frequently occurring and densely populated weeds of wheat in Pakistan (Siddiqui and Bajwa, 2001). Shad and Siddiqui (1991) observed that the grain yield of wheat declined with the increase in weed density under both rainfed as well as irrigated conditions.

Singh et al. (2003) studied effects of *Ageratum conyzoides* on wheat. They found that effects of soil previously infested with this weed, amended soils, residues of leaves and their extracts were inhibitory, compared to respective control; on root/shoot length and seedling dry weight of wheat. It was concluded that leaves residue of *Ageratum conyzoides* are phytotoxic to wheat by releasing phenolics into soil.

Singh et al. (2004) observed *Chenopodium album, Melilotus abla, Me]ilotus indica, Medicago denticu]ata, Lathyrus aphaca, Vicia sativa, Vicia hirsuta, Fumaria parvitlora, Anallis arvensis* and *Coronopus didymus* in wheat field.
Mishra et al. (2005) reported that wheat field was infested mainly with *Chenopodium album* (88.6%) and *Physalis minima* (8.5%).

Hossain et al. (2010) observed that the major weeds affecting the wheat crop in Bangladesh are *Oxalis europaea, Cynodon dactylon, Eleusine indica, Digitaria sanguinalis, Cyperus rotundus, Chenopodium album, Physalis heterophylla, Vicia hirsuta, Hedyotis corymbosa* and *Stellarla media* and they also noted that wheat fields are normally infested by between 18 and 22 types of weed species belonging to 11-12 families. Among them, *Oxalis* spp. was the most important, accounting for 27-33% of the total weed vegetation.

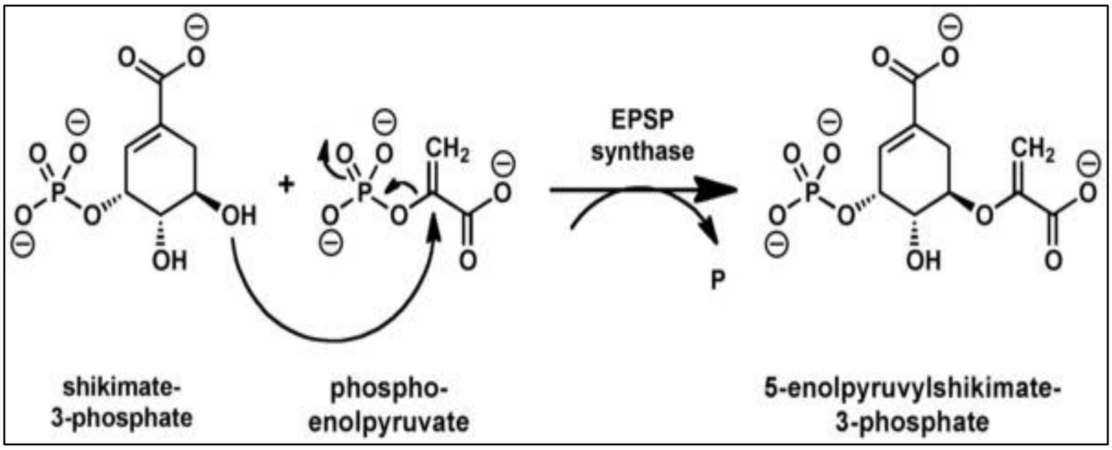
Haque (2011) identified, seventeen weed species belonging to nine families in wheat crop at the Bangladesh Agricultural University Farm. Among them *Chenopodium album, Vicia sativa, Cynodon dactylon, Cyperus rotundus, Eclipta alba and Lindernia procumbens* were dominant.

2.2 Effect of Glyphosate application on growth and yield of wheat

Glyphosate, or N-(phosphonomethyl) glycine, is a broad-spectrum, nonselective and post-emergence herbicide, used as an active ingredient in several weed killing products since 1970. Due to its effectiveness against wide variety of plants, glyphosate has been nominated as the once-in-a-century herbicide, and currently, it is one of the most commonly used herbicide in agricultural and non-agricultural cultivation systems in developed countries. When ending up in the soil, glyphosate is quickly adsorbed to soil particles and has a low probability of leaching along with surface waters or downwards into the soil profile. For these reasons, glyphosate has generally been regarded as an environmentally safe herbicide.

The active ingredient, glyphosate, is the compound that actually kills weeds. The Roundup Ultra label states that the active ingredient is “Glyphosate, N-(phosphonomethyl)glycine, in the form of its isopropylamine salt”. The term ‘glyphosate’ is the common name of the chemical, whereas ‘N-(phosphonomethyl) glycine’ is the chemical name that provides information about the actual chemical structure of the herbicide. Regardless of the brand you purchase, the active ingredient for all glyphosate products is exactly the same.

Glyphosate is used in plant production as a non-selective herbicide and harvest aid. Laboratory and field experiments were performed, which aimed at determining the effect of pre-harvest desiccation on grain quality and volunteer winter wheat. The short-term effects of the herbicide glyphosate (1.25−10 mM) on the growth, nitrogen fixation, carbohydrate metabolism, and shikimate pathway were investigated in leaves and nodules of nodulated lupine plants. All glyphosate treatments decreased nitrogenase activity rapidly (24 h) after application, even at the lowest and sublethal dose used (1.25 mM). This early effect on nitrogenase could not be related to either damage to nitrogenase components (I and II) or limitation of carbohydrates supplied by the host plant. In fact, further exposure to increasing glyphosate concentrations (5 mM) and greater time after exposure (5 days) decreased nodule starch content and sucrose synthase activity but increased sucrose content within the nodule. These effects were accompanied by a great inhibition of the activity of phosphoenolpyruvate carboxylase (PEPC). There were remarkable and rapid effects on the increase of shikimic and protocatechuic (PCA) acids in nodules and leaves after herbicide application. On the basis of the role of shikimic acid and PCA in the regulation of PEPC, as potent competitive inhibitors, this additional effect provoked by glyphosate on 5-enolpyruvylshikimic-3-phosphate synthase enzyme (EPSPS) inhibition would divert most PEP into the shikimate pathway, depriving energy substrates to bacteroids to maintain nitrogen fixation. These findings provide a new explanation for the effectiveness of glyphosate as a herbicide in other plant tissues, for the observed differences in tolerance among species or cultivars, and for the transitory effects on glyphosate-resistant transgenic crops under several environmental conditions.



Preharvest applications of glyphosate control weeds that interfere with mechanical harvest of wheat, accelerate wheat dry-down, which allows more timely harvest, and potentially reduces grain drying costs with no effect on grain quality (Clarke, 1981; Darwent et al., 1994).

However, applying glyphosate preharvest in wheat intended for seed is not currently labeled. Many farmers, however, produce their own wheat for seed to reduce costs. In some cases, this wheat received preharvest applications of glyphosate. Also, there is a possibility that glyphosate applied against label requirements to seed production fields could potentially cause emergence problems.

O'Keefe and Makepeace (1985) found that applications at rates to 4.32 kg ha^{-1} are made between 7 and 17 days prior to harvest without affecting seed yield, 1000-seed weight, crude protein. Similarly, germination is generally not affected (O'Keefe and Makepeace 1985), although a slight depression was noted in one study (Sheppard *et al.* 1982).

In Canada, investigations by Clarke (1981) at Swift Current, Saskatchewan have shown that the drydown of wheat was not hastened by preharvest applications of glyphosate.

Clemence (1989) investigated that glyphosate is registered in a number of European countries for use in preharvest applications for the control of perennial weeds, such as quackgrass (Elytigia repens (L.) Nevski).

According to Darwent and Drabble (1990), in Canada, preharvest applications of glyphosate have been shown to effectively control quack grass, as well as Canada thistle (*Cirsium arvense* L).

Cessna et al. (1994) observed that information on effects of preharvest applications of glyphosate on the drydown, seed yield and seed quality of wheat grown under Parkland zone conditions is required to facilitate their use for desiccation and/or perennial weed control. Therefore, in this study, we compared the effect of glyphosate applied at several rates and stages of crop maturity, as measured by seed moisture contents, on the seed and foliage drydown, seed yield and seed quality of spring wheat with that from control plot that were either windrowed at the time of glyphosate application or direct cut when mature. Residues of glyphosate, and its major metabolite, aminomethylphosphonic acid (AMPA), in the seed and straw harvested in this study were also measured. These measurements are reported elsewhere.

Darwent et al. (1994) conducted an experiment to find out the effect of preharvest applications of glyphosate on the drying, yield and quality of wheat. The experiments conducted from 1988 ISSO at four locations in the Parkland zone of western Canada, the drydown of seed and foliage, seed yield, seed quality and baking quality of wheat (*Titicum aestivum* L.) following preharvest applications of glyphosate. They found that seed yields were generally greater from plots to which glyphosate was applied than from windrowed control plots.

Glyphosate has been shown to affect seed germination or seedling quality when applied directly to seeds (Hassan 1988; Young et al. 1984) or applied as a preharvest application (Baur et al., 1977; Bovey et al. 1975). Other research has indicated little or no inhibition of seed germination of several crop species, including wheat with preharvest glyphosate ap- plication; however, phytotoxic effects on seedlings have been noted (Baur et al., 1977; Darwent et al., 1994; Sprankle et al., 1975). Glyphosate applied directly to harvested d wheat seeds did not affect seed germination, but the length of seedling roots and shoots were reduced (Hassan 1988).

Another experiment conducted by Darwent et al. (2000) to identify the effect of preharvest applications of glyphosate on the drying, yield and quality of canola. Glyphosate was applied in early August to early September at rates of 0.45, 0.90 and 1.70 kg acid equivalent ha^{-1} to canola with seed moisture contents ranging from 79 to 12%. Seed and foliage moisture drydown were not enhanced by glyphosate treatment. Glyphosate treatments generally had little or no effect on canola seed yields, seed weight, seed germination, green seed content.

2.3 Effect on phosphorus availability in grey terrace soils

Available P status of Bangladesh soils is in general poor. The soils of Bangladesh contained P below the critical level and 35% of the soils contained P above the critical level but below the optimum level reported by Portch and Islam (1984). Bhuiyan (1988) stated that available P of Bangladesh soils ranged from 2 to 14 ppm with a mean value of 12 ppm. Islam (1992) founded that available P determined by the Agro Service International method varied from 2 to 18 ppm in 29 soil series from all over the country; most of them were below the critical level (12 ppm).

Egashira and Yasmin (1990) reported that the total P contents of all of the 10 floodplain soils of Bangladesh were well above the critical level and that the soil of terrace area had the content just above the critical level, and they reported that total P was enough to sustain the normal growth of rice. Depending on the clay content, in the soils of non-calcareous Tista and Brahmaputra floodplains and Piedmont alluvial plains, the available P contents determined by the Olsen method by Egashira and Yasmin (1990) were above the critical level, whereas they were below the critical level in the soils of calcareous Ganges river floodplain and Barind tract.

Phosphorus (P) is an essential nutrient for plant growth. The low concentration (100 - 3000 mg P/kg) and solubility (<0.01 mg P/L) of P in soils, however, make it a critical nutrient limiting plant growth. The components, forms, availability, and cycling of P in soil are determined by complex and interrelated soil, chemical, and biological processes. Soil P exists in inorganic and organic forms. Inorganic P forms are dominated by hydrous sesquioxides, amorphous, and crystalline Al and Fe compounds in acidic, non-calcareous soils and by Ca compounds in alkaline, calcareous soils. Organic P forms include relatively labile phospholipids and fulvic acids; more resistant forms are comprised of inositols and humic acids. In natural ecosystems, P availability in soil is controlled by the sorption, desorption, and precipitation of P released during weathering and dissolution of rocks and minerals of low solubility. Soil P availability is generally inadequate for crop needs in production agriculture, thus, P is added as fertilizers or animal manures to build-up or maintain soil P availability at predetermined optimum levels.

This paper describes these processes occurring in the soil, how they are affected by the combination of glyphosate application, and how we attempt to optimize soil P availability for crop production. For the limiting source and fixing characters of phosphate fertilizers, the process of making phosphorus available in essential. The experiment resulted that glyphosate has influence on P availability which might be attributed to the competition between the two negatively charged ions for positively charged clay micelle (Cornish, 1992).

Phosphorus makes a significant contribution to the cost of producing cereals and the price of phosphate fertilizer can be expected to increase in the future as some new users of phosphate fertilizer, principally in Asia, enter the market; the high grade phosphate rock reserves are being depleted and lower grade ores are being mined. The cost of transporting ores and fertilizer products may also increase along with depletion of oil reserves. At the same time there will be increasing demands on world food production by the natural increase in the population of the world (Constant and Sheldrick, 1991; Strangel and Von Uexkull, 1990). The uptake and utilization of phosphorus in the field are influenced by genotype and the factors which affect water use efficiency (French and Schultz, 1984) including soil temperature (Barrow, 1974), and planting date (Batten,1976).

Earlier the original source of phosphorus (P) fertilizer was bones; as time passes, the supply of P fertilizer will get exhausted. Today, rock phosphate is the only raw material in the form of P fertilizers. There are two types of rock phosphates: igneous and sedimentary; both have the same phosphate mineral, i.e., calcium phosphate of apatite group. There are many commercially available P fertilizers like rock phosphate, phosphoric acid, calcium orthophosphates, ammonium phosphates, ammonium polyphosphate and nitric phosphates. There are rich deposits of phosphate found in Mongolia and Peru that will fulfill the need in the future. Florida phosphate industry becomes one of the major producer and exporter of phosphate fertilizer due to good transportation and industrial infrastructure facility in America and also because a substantial layer of phosphate is only 15 to 50 feet below a soft overburden. The phosphate mining in Central Florida overshadowed other sources because of low cost of mining, large deposits and the good quality of phosphate content of Florida rock. Florida is presently providing approximately 75% of the nation's supply of phosphate fertilizer and about 25% of the world supply. In 2000, mining operations began in Ontario, Canada, of North America.

Interaction effect of glyphosate, plant back period, phosphorus and soil type greatly influence the phosphorus concentration in soil. Glyphosate is the most extensively used pesticide worldwide. In addition to raising eco-toxicological concerns, the use of glyphosate adds phosphorus (P) to agricultural landscapes, influencing the accumulation and cycling of P in soil and nearby surface waters. Estimating the supply of P derived from glyphosate use, both globally and in the US alone, we show that trends have markedly increased over the past two decades. Across the US, mean inputs of glyphosate-derived P increased from 1.6 kg P km^{-2} in 1993 to 9.4 kg P km^{-2} in 2014, with values frequently exceeding 20 kg P km^{-2} in areas planted with glyphosate-resistant crops. Although still a minor source of P relative to fertilizers, P inputs from glyphosate use have now reached levels comparable to those from sources for which P regulations were initiated in the past. We thus argue for greater recognition of glyphosate's influence on P flow in watershed research and management.

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

3.1 Location of the experiment

The field experiment was conducted at the Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh, for the rabi season of 2019-2020. The physical characteristics and chemical status of the initial soil are shown in Tables 1 and 2, respectively. The experimental site is located at the Centre of the agro ecological zone of Madhupur tract (AEZ-28) at about 23° 59′ 15″ north latitude and 90° 24′ 20″ east longitude having a mean elevation of 8.6 m above mean sea level. The soil belongs to the Chhiata series of the Grey Terrace soils (*Aeric Albaquept*) under the order of Inceptisols in the USDA Soil Taxonomy (Huq and Shoaib, 2013). The morphological and taxonomical characteristics of the experimental site are shown in Appendix IV. The textural class was clay loam having soil pH 6.2 and the land type is medium high.

3.2 Climatic condition of the experimental site

From late November to mid-March, the minimum and maximum temperatures were in the lowest range whereas the periods from December to May are virtually dry. The relative humidity (%) varied between day and night of which at day time relative humidity (%) was about 90 (%) and at night it fluctuated to a wide range from 43 to 85% in February and March, respectively. (Appendix II & III).

3.3 Planting materials

The crop was wheat (*Triticum aestivum* L.) *cv.* BARI gom-26 which was collected from the Wheat Research Centre (WRC) of BARI, Gazipur.

3.4 Experimental treatments and design

The experiment was laid out in a split-split plot design with three replications. The experimental design was performed as follows: undisturbed soil ZT: a single slit was open with furrow opener of strip planter developed by FMPE division, BARI. The phosphorus doses used were minimum and high phosphorus respectively 5 kg ha^{-1} and 30 kg ha^{-1}. The glyphosate doses were 0, 1.25 and 3.75 L ha^{-1}. Glyphosate was applied 2 and 7 days before sowing. Phosphorus applied in sub plots and glyphosate in sub-sub plots. The unit plot size was 3m × 3.15m. The fertilizer doses for wheat were N_{140} K_{51} S_{12} Zn_2 $B_{0.5}$ kg ha^{-1} based on higher yield goal. The fertilizer requirements were calculated on soil test basis. One third urea, whole amount of triple superphosphate (TSP) and cowdung were applied during final land preparation. The rest of the urea, MoP, gypsum, and $ZnSO_4$ were applied in two equal splits at 25 days after sowing (DAS) and 45 DAS. Every split application of fertilizers was followed by irrigation. Another supplemental irrigation was applied at 65 DAS, while other intercultural operations were done as and when necessary. Weeds in plots were controlled partially by hand weeding at 20 DAS and 28 DAS for full elimination of weeds. The soil moisture was monitored intensively with gravimetric method (Black 1965). Wheat (*cv.* BARI gom 26) seeds were sown on the 05 December 2019 followed by irrigation. The row spacing maintained for wheat was 20 cm. The wheat was harvested on 05 April 2020.

3.5 Morphological and taxonomical characteristics of the experimental site

This experiment was conducted in BARI, Gazipur, Geographical position, soil type, taxonomical classification of soil shown in Appendix IV.

3.6 Physical, chemical and microbial characteristics of the initial soil of the experimental plot

The soil of the experimental plot under the agro- ecological zone, Madhupur Tract (AEZ-28), which falls into Shallow Red Brown Grey Terrace Soils. Soil samples were collected from the experimental plots to a depth of 0-15 cm from the surface and was analyzed in the laboratory. The soil was having a texture of clay loam with pH 5.7. The morphological characteristics of the experimental field and physical, chemical and microbial properties of soil are given in Table 1 and 2.

Table 1. Physical characteristics of the initial soil of the experimental plot

Textural class	Clay loam
Bulk density (g cm^{-3})	1.6
Particle density (g cm^{-3})	2.6
Total porosity (%)	37.9
Moisture content at field capacity (%)	26.0

Table 2a. Physical properties of initial soil during experiment (2019-2020)

Soil Depth (cm)	Moisture content (%)			Bulk density (g/cc)	Particle size (%)		
	0.3 bar (FC)	1 bar	2 bar		Sand	Clay	Silt
0-10	31.8	24.6	20.0	1.45	35.4	37.4	27.4
10-20	32.3	26.2	22.6	1.49	34.4	39.4	26.3

Table 2b. Chemical properties of initial soil during experiment (2019-2020)

Soil depth (cm)	Ph	OM	Total N	P ($\mu g\ g^{-1}$)	K (meq 100 g^{-1})	S	Zn	B
		%				$\mu g\ g^{-1}$		
0-10	5.7	1.3	0.069	17.2	0.13	11.9	1.82	0.12
10-20	5.8	1.2	0.063	15.8	0.14	11.2	1.76	0.12
Critical level	-	-	-	7.0	0.12	10	0.60	0.20

Table 2c. Microbial properties of initial soil during experiment (2019-2020)

Sample depth (cm)	MBC	MBN
	($\mu g\ g^{-1}$)	
10	420.0	128.7

3.7 Agronomic Data Collection

Emergence time data were collected. Germination percentage was also recorded which was calculated on the basis of hypocotyls appeared above the surface of soil.

Percentage of seed germination (%): $\frac{x}{n} \times 100$

where x is number of hypocotyls appeared above the soil surface and n is total seeds sown.

3.8 Phenological observation of wheat

Ten sample plants from each plot were selected from 1 m^2 quadrates (quadrates were set just after sowing) to determine various phenological characters such as plant height (cm), number of leaves $plant^{-1}$, leaf length, shoot dry weight, number of pods $plant^{-1}$, pod length, number of seeds pod^{-1}, green pod yield, seed yield and stover. The plant height was measured in fresh using a ruler from the point near to soil surface to the longest portion of the plant tip at maturity and then average was calculated. The parameters such as number of branches $plant^{-1}$, number of pods $plants^{-1}$, number of seeds pod^{-1}, fresh weight of shoot and dry biomass of shoot and the grain yields (kg ha^{-1}) were assessed.

3.9 Collection and analysis of soil samples

Besides, collection of initial soil samples, soil samples were collected at 15 DAS, 30 DAS and at harvest. The collected soil samples were dried at room temperature mixed thoroughly, grinded, sieved with a 2 mm sieve and preserved in plastic containers for subsequent laboratory analysis. The post-harvest soil samples were then analyzed for SOM, total N and P. The SOM was determined by wet oxidation (Jackson, 1973), total N by a modified Kjeldahl method (Page et al., 1989) and total P by using the $SnCl_2$ reduction method (Black, 1965). The pH was determined through glass electrode pH meter method (Jackson, 1962), K and S were determined through NH_4OAC method (Hanlon and Johnson,1984) and turbidimetric method (Sperber, 1984), respectively. Micronutrients were analyzed using atomic absorption spectrophotometer. Particle size distribution of the initial soil was analysed by the hydrometer method (Black, 1965) and the textural class was determined using the USDA texture triangle. The bulk density of the soil samples was determined by core sampler method (Karim et al., 1988). Moisture content was determined by gravimetric method (Black, 1965). Field capacity was measured though pressure plate method.

3.10 Statistical analysis

The data collected were subjected to descriptive statistics to calculate germination percentage by using MS-Excel spreadsheet version 2010. Statistics 10 program was employed to determine analysis of variance (ANOVA) of different phonological data of wheat and the mean values were compared with least significant difference (LSD) at value 0.05 (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The experiment was conducted from November, 2019 to March 2020 to find out the effect of glyphosate on growth characters and yield of wheat (BARI Gom-26). Data on different growth parameter, yield contributing parameters, yield parameters, weed biomass and phosphorus availability were recorded and statistically analyzed. The plant back period, applying glyphosate at 2 and 7 days before sowing and phosphorus doses are the replications.

4.1 Effect of glyphosate application at different days prior to soil tillage application (plant back period) on wheat emergence and yield contributing characters

Days to emergence (days) and germination (%)

Glyphosate applied at 2 days prior to tillage application had varied yield contributing characters and yield of wheat. Glyphosate applied at 2 days prior to tillage application had varied days required to emergence ($p < 0.05$). Glyphosate applied at 2 days prior to tillage application required 1 day more to emergence. Seeds germination in plots under 2 days plant back period required 7.9 days, while 7 days plant back period required 7.1 days (Table 3a).

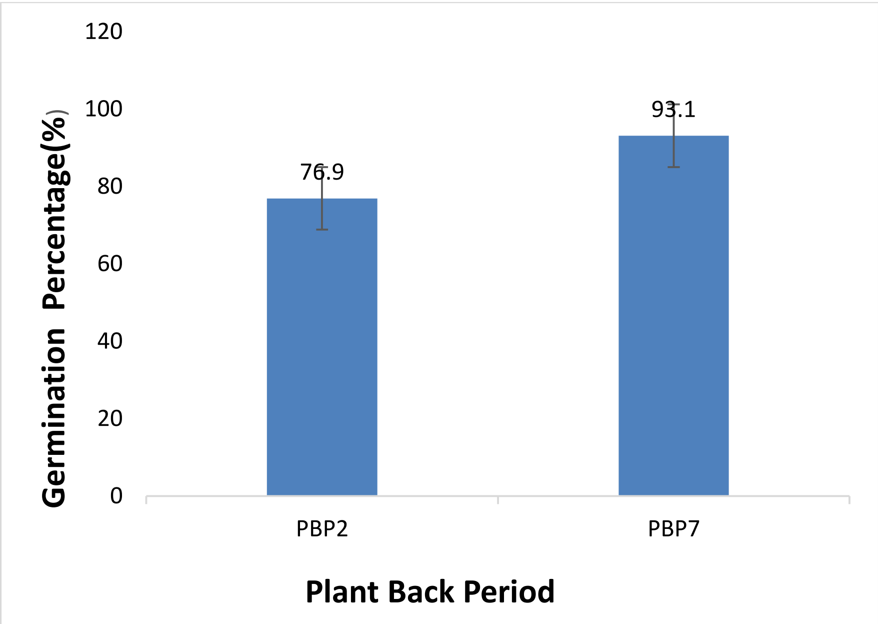


Fig 1. Effect of plant back period of glyphosate application on germination percentage. Here, PBP=Plant back period.

Table 3a. Effect of glyphosate application at different days prior to soil tillage application (plant back period) on yield contributing characters of wheat

Plant back period	Days to emergence (Days)	Germination %	Leaves no /plant at 15 DAS	Leaf length at 15 DAS (cm)
PBP2	7.9	76.9	3.1	11.2
PBP7	7.1	93.1	3.7	13.5
$LSD_{0.05}$	0.5	6.3	0.1	1.1
CV (%)	7.56	5.20	5.78	6.20

PBP-Plant back period, DAS-Days After Sowing

When the glyphosate was applied 7 days before land preparation, germination was about 16% higher over glyphosate applied 2 days before land preparation (Table 3a). However, the plant back period effect on germination (%) was significant ($p < 0.05$).

Leaves/plant (no.) and leaf length of wheat (cm)

The plant back period had varied leaves/plant ($p > 0.05$) and leaf length of wheat ($p < 0.05$) at 15 DAS. The leaves/plant and leaf length of wheat at 15 DAS were also higher at glyphosate applied 7 days before land preparation. The leaf length was 13.5 cm at 15 DAS under plant back period 7 days which was 2.3 cm higher than leaf length recorded at 2 days plant back period.

Plant height (cm)

The plant heights at 30 DAS and at maturity were higher when glyphosate was applied 7 days before than when applied before 2 days of land preparation. The plant height at maturity was about 19% higher when glyphosate was applied 7 days before than when applied before 2 days of land preparation (Table 3b). The difference in plant height was wider at 30 DAS.

Spikes /m^2

Spike per m^2 was varied due to plant back period ($p < 0.05$). Spikes m^2 were also higher at the treatment when glyphosate was applied 7 days before than when applied before 2 days of land preparation (Table 3b).

Grain yield (t ha^{-1})

Plant back period had varied yield of wheat ($p < 0.05$). Accordingly, the grain yield of wheat was higher at the treatment when glyphosate was applied 7 days before than when applied before 2 days of land preparation (Table 3b).

Weed biomass (g m^{-2})

The dry weed biomass per m^2 was also influenced by dates of application of the glyphosate herbicide. The weed biomass was about 19.7% lower in the treatment when glyphosate was applied 7 days before than when applied before 2 days of land preparation (Table 3b).

Phosphorus concentration at 15 DAS

Though the available P was significantly different by glyphosate application at different days before land preparation ($p > 0.05$), the higher P at available form was recorded at the treatment when glyphosate was applied 7 days before than when applied before 2 days of land preparation (Table 3b).

Table 3b. Effect of glyphosate application at different days prior to soil tillage application (plant back period) on yield, yield contributing characters of wheat and available P concentration in soil

Plant back period	Plant height at 30 DAS (cm)	Plant height at maturity (cm)	Spike (m^{-2})	Grain yield ($t\ ha^{-1}$)	Available P at 15 DAS ($mgkg^{-1}$)	Dry weed biomass ($g\ m^{-2}$)
PBP2	31.8	91.2	31	4.3	36.7	12.2
PBP7	38.2	108.4	37	5.1	32.9	14.6
$LSD_{0.05}$	0.01	0.6	2.5	0.01	0.17	0.04
CV (%)	6.93	8.20	8.42	9.76	8.53	9.44

PBP-Plant back period, DAS-Days After Sowing

4.2 Effect of glyphosate doses on yield and yield contributing characters of Wheat

Days to emergence (days) and germination (%)

Glyphosate dose had varied days to emergence ($p < 0.05$). The use of high dose of glyphosate (3.75 L ha^{-1}) takes more than 3.8 days for emergence of wheat than no use of glyphosate, while it was 3.2 days more when compared with recommended glyphosate dose (Table 4a). The germination percentage also varied due to different glyphosate doses ($p<0.05$). The use of glyphosate at high dose (3.75 L ha^{-1}) hampered the germination percentage by about 25%, relative to no glyphosate use.

Plant height at 15 DAS

Plant height at 15 DAS was varied due to glyphosate application dose variation ($p < 0.05$). Plant height at 15 DAS was also suppressed by the higher dose of glyphosate (3.75 L ha^{-1}). The highest plant height at 15 DAS was the lowest (30.9 cm) when high dose of glyphosate was used and medium plant height (34.3 cm) was recorded under recommended glyphosate dose (Table 4a).

Leaves/plant and leaf length (cm)

Leaves/plant was affected by glyphosate dose while the leaf length was drastically reduced due to high dose of glyphosate application ($p < 0.05$). The lowest leaf length (8.4 cm) was recorded from high dose of glyphosate dose which was 5.1 cm lower than the recommended dose of glyphosate (Table 4a).

Plant height

Plant height of wheat was varied due to glyphosate application ($p< 0.05$). Plant height at 30 DAS was reduced by 9 cm at high dose of glyphosate, relative to no glyphosate use. Recommended dose also had decreased leaf length and plant height at 30 DAS. However, plant height at maturity was not influenced by glyphosate application (Table 4b), indicating that the effect of glyphosate application on plant height was minimized at maturity of wheat crop.

Spike m^{-2}

Use of high doses of glyphosate herbicide had effect on spike number per unit area (Table 4b). However, the spike per unit area was reduced due to high dose of glyphosate.

Yield of wheat (t ha^{-1})

Use of the herbicide at the recommended dose didn’t affect yield of BARI gom 26. On the other side, use of high doses of glyphosate herbicide also reduced yield of wheat ($p < 0.05$). High rate of glyphosate with high level of fertilizer in the mixed soil had phytotoxic effect on the shoot dry weight of wheat plant. The lower shoot dry weight found in plants grown in soils with glyphosate and high rate of fertilizer applied can be attributed to disturbed roots by highly glyphosate concentrated soils. The disturbed roots or reduced number of roots could not be able to uptake adequate amount of nutrients from soil. Again, a glyphosate interrupts EPSP activity for not producing proper amount of chlorophyll and the plants could not increase its biomass in shoots (Yamada and Castro, 2007).

Phosphorus concentration at 15 DAS

The concentration of available P at 15 DAS was affected by glyphosate use. The high dose and recommended dose of glyphosate increased available P by about 86.6% and 37.80%, respectively, relative to no glyphosate use (Table 4b).

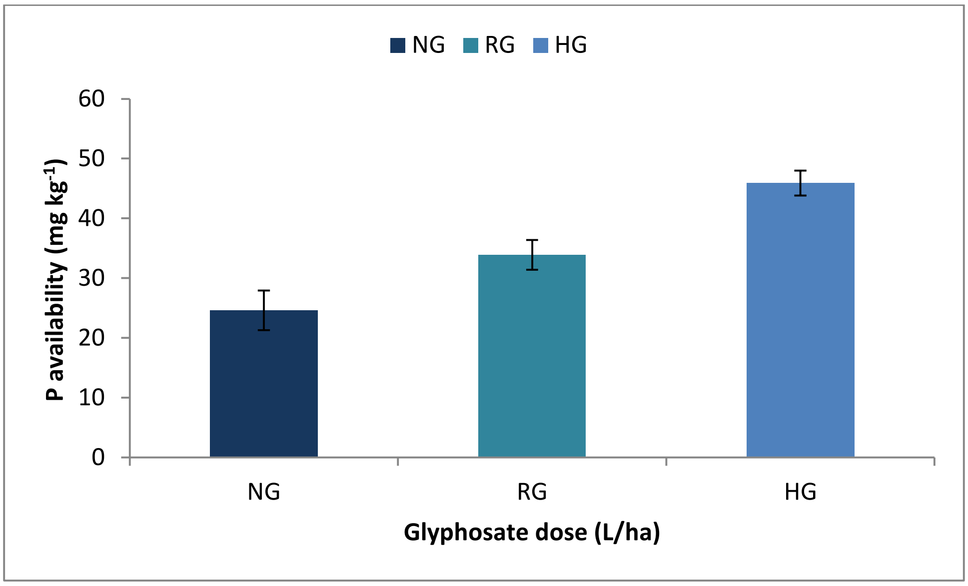


Fig 2. Effect of glyphosate application on phosphorus concentration (mg kg^{-1}) in soil; Here, NG- No glyphosate, RG- Recommended Glyphosate (1.25 L/ha), HG-High glyphosate (3.75 L/ha)

The mechanism through which glyphosate could increase soil P availability to crops is through adsorption to the same soil sites as phosphate ions. Because of their chemical resemblance, glyphosate and phosphate can compete for the same (limited) sorption sites, with phosphate-rich soils and fertilization (i.e., increasing P saturation) potentially reducing glyphosate sorption and enhancing its mobility (Gimsing et al., 2004; vereecken, 2005). Moreover, intense glyphosate use could also increase the occupancy of sorption sites, potentially favoring phosphate mobility; that is, even if P-glyphosate itself never reaches a water body, glyphosate–phosphate competition for sorption sites could potentially cause greater phosphate availability in soils.

Weed dry biomass

The dry weed biomass per m^{-2} was also influenced by glyphosate application at higher doses (Table 4b). The weed biomass was 76.14% lower in the high glyphosate treatment than no glyphosate treatment (Table 4b). However, the recommended dose of glyphosate (1.25 L ha^{-1}) also had reduced weed biomass. Singh et al. (2011) recorded similar result in selected four weed species common to Florida citrus. In another experiment, Singh and Sharma (2008) also recorded reduced weed biomass with the application of glyphosate.

Table 4a. Effect of glyphosate dose application on yield contributing Characters and yield of wheat

Treatment	Days to emergence (days)	Germination %	Leaves no/plant at 15 DAS(cm)	Leaf length at 15 DAS (cm)	Plant height at 30 DAS (cm)
NG	9.9	93.1	4.5	15.2	39.9
RG	6.7	87.5	3.4	13.5	34.3
HG	6.1	74.5	2.3	8.4	30.9
$LSD_{0.05}$	1.3	2.2	0.2	1.53	4.0
CV (%)	7.6	8.42	5.66	9.47	7.74

Here, NG-No glyphosate, RG-Recommended glyphosate (1.25 L ha^{-1}), HG-High glyphosate (3.75 L ha^{-1})

Table 4b. Effect of glyphosate application on yield contributing characters, yield of wheat and available P concentration in soil

Treatment	Plant height at maturity (cm)	Spike m^{-2}	Grain yield (t ha^{-1})	Available P (mg kg^{-1})	Dry weed biomass (g m^{-2})
NG	103.4	361.1	4.9	24.6	21.8
RG	100.6	336.0	4.8	33.9	13.2
HG	95.5	326.6	4.4	45.9	5.2
$LSD_{0.05}$	8.4	32.4	0.4	4.3	1.1
CV (%)	7.92	8.42	9.76	8.56	9.44

Here, NG-No glyphosate, RG-Recommended glyphosate (1.25 L ha^{-1}), HG-High glyphosate (3.75 L ha^{-1}).

4.3 Effect of different levels of phosphorus application on yield contributing characters and yield of wheat

Phosphorus dose have varied germination percentage ($p > 0.05$), where high phosphorus requires 1 day more to emergence than minimum phosphorus, leaf length ($p > 0.05$), plant height at 30 DAS ($p < 0.05$) and at maturity ($p > 0.05$). Plant height at 30 DAS had 18.4 % higher with increased dose of P application. Use of high dose of P increased yield of wheat ($p > 0.05$). The yield of wheat was 6.12% higher at the increased dose of P application than the yield obtained at minimum dose of P application. The use of phosphorus at high dose hampered the germination percentage by about 3.0%, relative to minimum dose of P use. However, the weed biomass was not increased by the increased rate of P application (Table 5b).

Phosphorus concentration at 15 DAS

Phosphorus containing fertilizer applied at higher dose had very high P at available form (64.3% higher at high P dose than the P at minimum P dose) (Table 5b).

Table 5a. Effect of different levels of phosphorus application on yield contributing Characters and yield of wheat

Phosphorus dose	Days to emergence (days)	Germination %	Leaves no/ plant at 15 DAS	Leaf length at 15 DAS (cm)	Plant height at 30 DAS (cm)	Plant height at maturity (cm)
High P	8.0	83.5	3.4	12.7	38.6	102.8
Minimum P	7.1	86.5	3.4	11.9	31.5	96.8
$LSD_{0.05}$	0.5	0.9	0.2	1.7	6.7	6.4
CV (%)	6.72	7.91	6.05	5.81	5.75	7.3

High P =30 kg ha^{-1}; Minimum P = 5 kg ha^{-1}

Table 5b. Effect of different levels of phosphorus application on yield contributing characters, yield of wheat and on available P concentration in soil

Phosphorus	Spike m^{-2}	Grain yield (t ha^{-1})	Available P at 15 DAS (mg kg^{-1})	Dry weed biomass (g m^{-2})
High P	341.9	4.9	51.3	13.3
Minimum P	340.6	4.6	18.3	13.6
$LSD_{0.05}$	26.6	0.43	5.60	0.36
CV (%)	8.42	9.76	8.53	9.44

High P =30 kg ha^{-1}; Minimum P =5 kg ha^{-1}

4.4 Interaction effect of dates of glyphosate application (plant back period) and glyphosate on yield contributing characters and yield of wheat

Days to emergence (days) and germination (%)

The interaction effect of dates of glyphosate application (plant back period) and glyphosate on days to emergence and germination percentage was significant ($p < 0.05$). Among the plant back period allowed for wheat crop emergence and plant growth, glyphosate applied 2 days before land preparation at higher dose of glyphosate required wheat seeds more days to emerge (10.5 days). The highest days to emergence was followed by glyphosate applied 7 days before land preparation at high glyphosate applied soils (Table 6a). The result indicated that higher concentration of glyphosate at surface soils hampered seedling emergence when not applied allowing more days for plant emergence and growth. The soils under high glyphosate applied at 2 days before land preparation had lowest germination percentage, leaves no/plant, leaf length at 15 DAS, plant height at 30 DAS and at maturity, spike m^{-2} and grain yield. The high rate of glyphosate may have phytotoxic effect on the leaf count of wheat plant when high rate of P fertilizer is also applied.

Leaves/plant and Leaf length at 15 DAS

The interaction effect of dates of glyphosate application (plant back period) and glyphosate dose on Leaves/plant and Leaf length at 15 DAS was significant ($p < 0.05$). Wheat plant growth has been hampered due to high dose of glyphosate application and low plant back period, where the numbers of leaves of wheat plants are reduced. The high rate of glyphosate with minimum plant back period reduced the leaf count in soil. The lowest leaves/plant and leaf length was recorded in 2 days plant back period applied with high dose of glyphosate. The phytotoxic effect of high doses of glyphosate herbicide might retard the growth of wheat and cause severe damage when seeds were planted with allowing minimum number of days as plant back period (Cornish, 1992; Varshney et al., 2012). However, the 7 days plant back period and recommended dose of glyphosate had optimum number of leaves and leaf length (Table 6a).

Plant height at 30 DAS and maturity

The high rate of glyphosate with minimum plant back period retarded plant heights both at 30 DAS and maturity stages (Table 6a and 6b). However, the effect of glyphosate dose and plant back period on plant height was minimized at maturity stage. Though the highest plant height was recorded from no glyphosate use at both maturity and at 30 DAS, the optimum plant height was recorded in recommended dose of glyphosate and 7 days plant back period. On the other hand, the lowest plant height was recorded in high dose of glyphosate and 2 days plant back period, may be because the phytotoxic effect of glyphosate inflicted on wheat seeds when sown at 2 days plant back period (Cornish, 1992; Varshney et al., 2012).

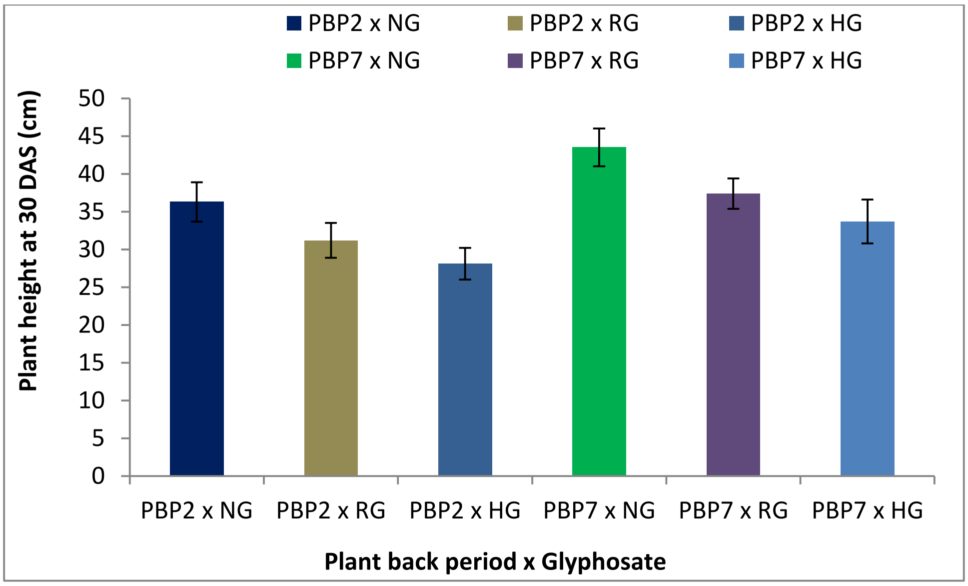


Fig 3. Interaction effect of glyphosate doses and dates of glyphosate application on plant height at 30 DAS. Here, PBP-Plant back period; NG-No-glyphosate; RG-recommended glyphosate (1.25 L ha^{-1}); and HG-High glyphosate (3.75 L ha^{-1})

Spike m^{-2}, grain yield (t ha^{-1}) and dry weed biomass (g m^{-2})

The high rate of glyphosate with minimum plant back period had varied spike/m^2 and grain yield of wheat (Table 6b). However, the effect of glyphosate dose on plant height was higher when applied at recommended dose with 7 days plant back period. Though the highest grain yield (5.4 t ha^{-1}) was recorded from no glyphosate use with 7 days plant back period, the yield at recommended dose of glyphosate and 7 days plant back period was statistically similar to no glyphosate use (5.3 t ha^{-1}). On the other hand, the lowest wheat grain yield was recorded in high glyphosate dose application at 2 days plant back period (Table 6b). Similar results due to low plant back period and high rate of glyphosate application in soils were recorded by Morillo et al. (2000) and Sheals et al. (2002). So, the phytotoxic effect of glyphosate for taking up by roots of wheat plants hampers physiological processes related to EPSPS enzyme and chlorophyll synthesis which ultimately reduce growth of wheat including leaf expansion and length increase (Morillo et al., 2000; Sheals et al., 2002). The dry weed biomass was significantly higher in the soils where no glyphosate was applied under both the dates of glyphosate application (plant back period). On the other hand, Lukangila et al. (2016) found no effect on glyphosate resistant weeds.

4.5. Interaction effect of dates of glyphosate application (plant back period) and glyphosate on phosphorus concentration in soil at 15 DAS

Interaction effect of dates of glyphosate application (plant back period) and glyphosate on P concentration in soil (at 15 DAS) was significant ($p<0.01$). The highest available P was recorded 48.41 and 43.4 mg kg^{-1} soil under the high glyphosate dose application at 2 days and 7 days plant back period respectively (Table 6b). The mechanism through which glyphosate could increase soil P availability to crops is through adsorption to the same soil sites as phosphate ions. Because of their chemical resemblance, glyphosate and phosphate can compete for the same (limited) sorption sites, with phosphate-rich soils and fertilization (i.e., increasing P saturation) potentially reducing glyphosate sorption and enhancing its mobility (Gimsing et al., 2004; vereecken, 2005). Moreover, intense glyphosate use could also increase the occupancy of sorption sites, potentially favoring phosphate mobility; that is, even if P-glyphosate itself never reaches a water body, glyphosate–phosphate competition for sorption sites could potentially cause greater phosphate availability in soils.

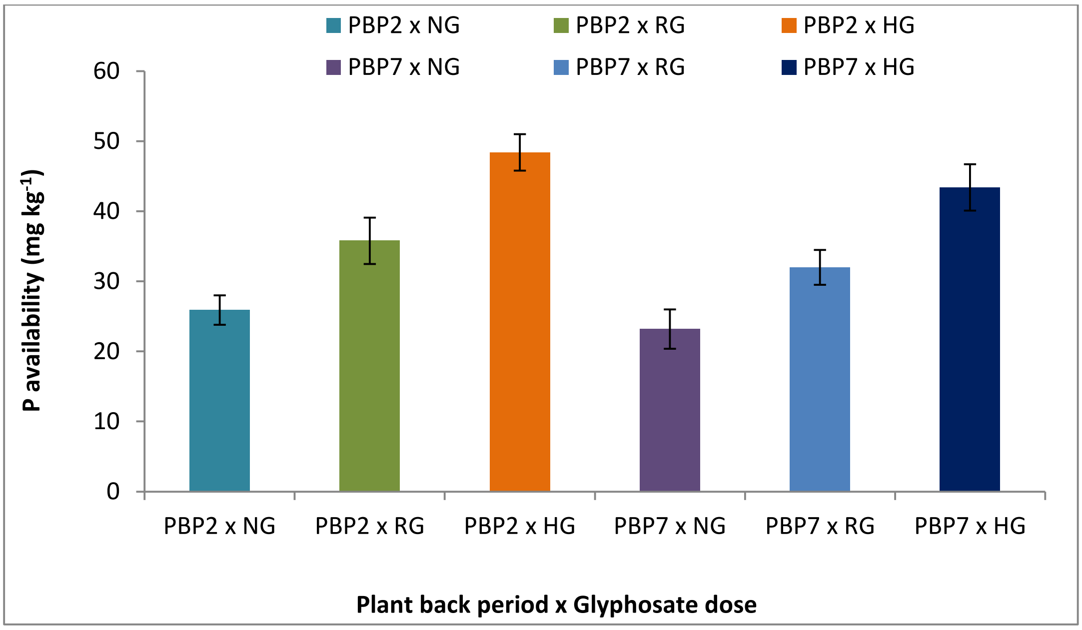


Fig 4. Interaction effect of glyphosate doses and dates of glyphosate application on available P concentration in soil. Here, PBP-Plant back period; NG-No-glyphosate; RG-recommended glyphosate (1.25 L ha^{-1}); and HG-High glyphosate (3.75 L ha^{-1}).

Table 6a. Interaction effect of glyphosate doses and dates of glyphosate application on yield contributing characters and yield of wheat

Treatment	Days to emergence (days)	Germination %	Leaves no/plant at 15 DAS (cm)	Leaf length at 15 DAS (cm)	Plant height at 30 DAS (cm)	Plant height at maturity (cm)
PBP2 x NG	6.4	84.3	4.1	13.8	7.7	94.5
PBP2 x RG	7.0	79.2	3.1	12.3	6.5	91.9
PBP2 x HG	10.5	67.4	2.1	7.7	5.1	87.3
PBP7 x NG	5.8	101.9	4.9	16.5	9.2	112.2
PBP7 x RG	6.4	95.8	3.7	14.7	7.8	109.2
PBP7 x HG	9.4	81.6	2.5	9.2	6.04	103.7
$LSD_{0.05}$	1.9	3.2	0.2	2.2	2.1	11.9
CV (%)	7.56	5.20	5.78	6.20	7.83	6.93

Here, PBP-Plant back period; NG-No-glyphosate; RG-recommended glyphosate (1.25 L ha^{-1}); HG-High glyphosate (3.75 L ha^{-1})

Table 6b. Interaction effect of glyphosate doses and dates of glyphosate application on yield contributing characters, yield of wheat and on available P concentration in soil

Treatment	Spike m^{-2}	Grain yield (t ha^{-1})	Available P At 15 DAS (mg kg^{-1})	Dry weed biomass (g m^{-2})
PBP2 x NG	330	4.5	25.8	19.8
PBP2 x RG	307	4.4	35.7	12.0
PBP2 x HG	299	4.0	48.4	4.7
PBP7 x NG	392	5.4	23.3	23.8
PBP7 x RG	365	5.3	32.1	14.4
PBP7 x HG	355	4.8	43.4	5.7
$LSD_{0.05}$	45.7	0.6	6.1	1.6
CV (%)	8.42	9.76	9.65	9.44

Here, PBP-Plant back period; NG-No-glyphosate; RG-recommended glyphosate (1.25 L ha^{-1}); HG-High glyphosate (3.75 L ha^{-1})

4.6 Interaction effect of phosphorus and glyphosate on yield contributing characters and yield of wheat

Effects on days to emergence (days) and germination (%),

The highest days to emergence was recorded in soils under high phosphorus and high glyphosate dose (10.2 days) which was followed by minimum P but high glyphosate applied soils. The result indicated that higher concentration of glyphosate at surface soils hampered seedling emergence. The soil under the no glyphosate application has the higher germination percentage. The use of glyphosate at high dose (3.75 Lha^{-1}) with high phosphorus dose hampered the germination percentage by about 25.3% relative to no glyphosate dose with minimum phosphorus.

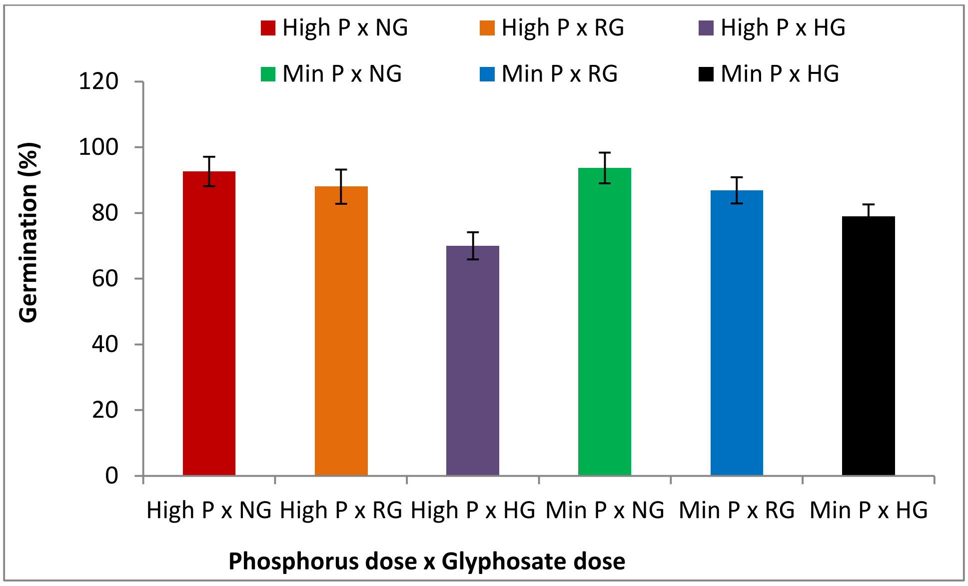


Fig 5. Interaction effect of phosphorus and glyphosate dose on germination percentage of wheat seed. Here, Min P-Minimum phosphorus; NG-no glyphosate; RG-recommended glyphosate; HG-high glyphosate

Effect on growth and yield parameters and dry weed biomass

The soils under no glyphosate combined with either high P or minimum P had highest germination percentage, leaves no/plant, leaf length at 15 DAS, plant height at 30 DAS and at maturity, spike m^{-2} and grain yield. However, the grain yield was not significantly different among the different combinations of P and glyphosate doses (Table 7a and b). The dry weed biomass was significantly higher in the soils where no glyphosate was applied under both the high and minimum P doses applied in soils.

4.7 Interaction effect of phosphorus and glyphosate on phosphorus concentration in soil

Interaction effect of P and glyphosate on P concentration in soil (at 15 DAS) was significant ($p<0.01$). The highest available P was recorded in high glyphosate dose and recommended glyphosate dose under high P dose treated soils (68.90 and 49.8 mg kg^{-1} respectively). The lowest available P was recorded in soil applied with minimum phosphorus no glyphosate (Table 7b).

The result indicated that glyphosate has influence on P availability which might be attributed to the competition between the two negatively charged ions for positively charged clay micelle (Cornish, 1992). Besides, the presence of high rate of glyphosate in the soil for a prolonged period reduced the shoot biomass of wheat by unleashing its phytotoxic effect on the growth of wheat plant (Yamada and Castro, 2007).

Table 7a. Interaction effect of phosphorus and glyphosate on yield contributing characters and yield of wheat

Treatment	Days to emergence (days)	Leaves/ plant at 15 DAS (cm)	Leaf length at 15 DAS (cm)	Plant height at 30 DAS (cm)	Plant height at maturity (cm)
High P x NG	6.3	4.5	15.7	42.7	106.1
High P x RG	7.6	3.4	13.5	38.2	103.9
High P x HG	10.2	2.3	8.9	34.8	98.3
Min P x NG	5.8	4.5	14.6	37.1	100.6
Min P x RG	6.8	3.6	13.5	30.3	97.2
Min P x HG	9.7	2.3	7.9	26.9	92.7
$LSD_{0.05}$	1.8	0.2	2.2	5.6	11.9
CV (%)	7.56	5.78	6.20	6.93	8.20

Here, High P-High Phosphorus; Min P-Minimum phosphorus; NG-No-glyphosate; RG-Recommended glyphosate; HG-High glyphosate

Table 7b. Interaction effect of phosphorus and glyphosate on yield contributing characters and yield of wheat and phosphorus concentration in soil

Treatment	Spike m^{-2}	Grain yield ($t\ ha^{-1}$)	Available P at 15 DAS ($mg\ kg^{-1}$)	Dry weed biomass ($g\ m^{-2}$)
High P x NG	360	5.2	35.3	22.3
High P x RG	337	4.9	49.8	12.9
High P x HG	329	4.5	68.9	4.7
Min P x NG	361	4.7	13.9	21.3
Min P x RG	335	4.7	33.1	13.6
Min P x HG	324	4.3	22.9	5.8
$LSD_{0.05}$	45.8	0.6	6.1	1.6
CV (%)	8.42	9.76	8.53	9.44

High P- High Phosphorus; Min P-Minimum phosphorus; NG-No-glyphosate; RG-Recommended glyphosate; HG-High glyphosate

4.8 Interaction effect of plant back period and phosphorus doses on yield contributing characters and yield of wheat

Days to emergence (days) and germination (%)

Among the plant back period allowed for wheat crop emergence and plant growth, glyphosate applied 2 days before land preparation at higher dose of phosphorus required wheat seeds more days to emerge (about 9 days). The highest days to emergence was followed by phosphorus applied 2 days before land preparation at high phosphorus applied soils (Table 8a). The result indicated that higher concentration of phosphorus at surface soils 2 days before land preparation hampered seedling emergence when not applied allowing more days for plant emergence and growth. The soils under high phosphorus applied at 7 days before land preparation had 17.4% higher germination percentage than the high phosphorus at 2 days before land preparation.

Effect on growth and yield parameters

The soils under minimum phosphorus applied at 2 days before land preparation had lowest leaves/plant, leaf length at 15 DAS, plant height at 30 DAS and at maturity, spike m^{-2} and grain yield. However, the grain yield was not significantly different among the different combinations of plant back period and phosphorus doses (Table 8a and 8b). The dry weed biomass was significantly higher in the soils where minimum phosphorus was applied 7 days before land preparation.

4.9 Interaction effect of plant back period and phosphorus doses on phosphorus concentration in soil at 15 DAS

The highest available P was recorded in high phosphorus dose (54.1 and 48.5 mg kg^{-1} soil in 2 days and 7 days plant back period, respectively). The lowest available P was recorded with min phosphorus dose (19.3 and 17.3 mg kg^{-1} soil in 2 days and 7 days plant back period, respectively) (Table 8b).

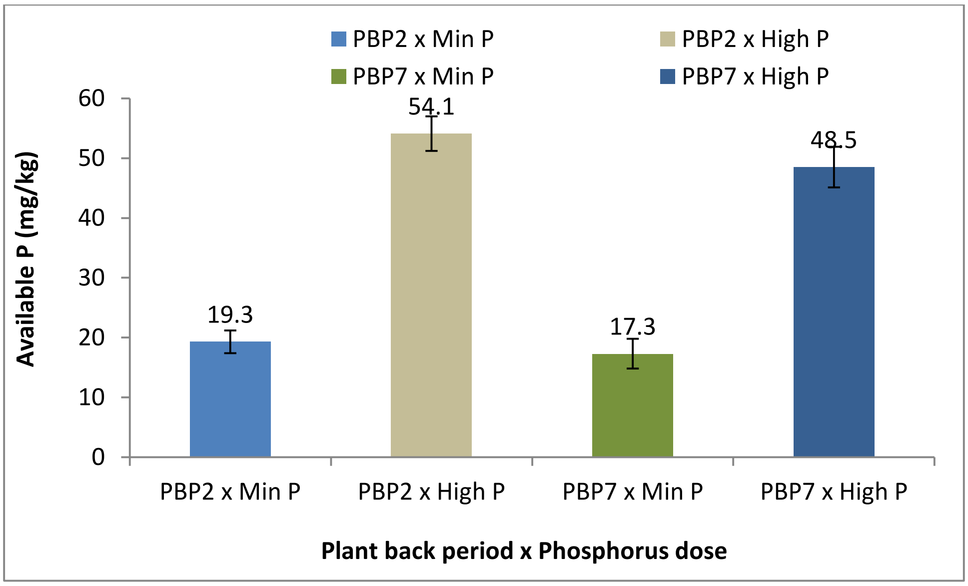


Fig 6. Interaction effect of plant back period and phosphorus doses on phosphorus availability in soil. Here, PBP-Plant back period, Min P-Minimum Phosphorus, High P- High Phosphorus

Table 8a. Interaction effect of plant back period and phosphorus doses on yield contributing characters and yield of wheat

Treatment	Days to emergence (days)	Germination %	Leaves/plant at 15 DAS (cm)	Leaf length at 15 DAS (cm)	Plant height at 30 DAS (cm)
PBP2 x Min P	7.5	78.3	3.1	10.9	25.6
PBP2x High P	8.4	75.6	3.1	11.6	35.1
PBP7 x Min P	6.7	94.8	3.7	13.0	34.3
PBP x High P	7.6	91.5	3.7	13.9	42.1
$LSD_{0.05}$	0.7	1.3	0.1	2.5	9.6
CV (%)	7.56	5.20	5.78	6.20	6.93

Here, PBP-Plant back period, Min P-Minimum Phosphorus; High P- High Phosphorus

Table 8b. Interaction effect of plant back period and phosphorus doses on yield contributing characters, yield of wheat and phosphorus availability in soil

Treatment	Plant height at maturity (cm)	Spike m^{-2}	Grain yield ($t\ ha^{-1}$)	Available P (ppm)	Dry weed biomass ($g\ m^{-2}$)
PBP2 x Min P	88.5	312	4.1	19.3	12.3
PBP2 x High P	93.6	313	4.5	54.1	12.1
PBP7 x Min P	105.2	370	4.9	17.3	14.8
PBP7x High P	111.6	371	5.3	48.5	14.5
$LSD_{0.05}$	9.1	37.6	0.6	7.9	0.5
CV (%)	8.20	8.42	9.76	9.82	9.44

Here, PBP-Plant back period, Min P-Minimum Phosphorus; High P- High Phosphorus

4.10 Interaction effect of plant back period, phosphorus doses and glyphosate doses on yield contributing characters and yield of wheat

Days to emergence (days) and germination (%)

The highest days to emergence was recorded in soils under high phosphorus, high glyphosate dose which applied on 2 days plant back period (10.7 days) followed by minimum P but high glyphosate applied soils in 2 days plant back period (10.2 days). The lowest days to emergence was recorded in soils under minimum phosphorus, no glyphosate dose which applied on 7 days plant back period (5.5 days). The result indicated that higher concentration of glyphosate at 2 days before in surface soils hampered seedling emergence. The highest germination percentage was recorded in soils under minimum phosphorus with no glyphosate dose which applied on 7 days plant back period followed by high

P but no glyphosate applied soils in 7 days plant back period. The lowest germination percentage was recorded in soils under high phosphorus, high glyphosate applied soils in 2 days plant back period.

Effect on growth and yield parameters

The soils under no glyphosate combined with either high P or minimum P in 7 days plant back period had highest germination percentage, leaves/plant, leaf length at 15 DAS, plant height at 30 DAS and at maturity, spike m^{-2} and grain yield. The grain yield was different among the different combinations of P doses, glyphosate doses and plant back period (Table 9a and b). The highest grain yield (5.7 t ha^{-1}) was found under no glyphosate with high phosphorus applied at 7 days plant back period followed by high P with recommended dose of glyphosate. The dry weed biomass was significantly higher in the soils where no glyphosate was applied under both the high and minimum P doses applied in soils at 2 days plant back period. Considering the results grain yield, available phosphorus and dry weed biomass, the recommended dose of glyphosate can be recommended here.

4.11 Interaction effect of plant back period, phosphorus doses and glyphosate doses on phosphorus concentration in soil at 15 DAS

The highest available P was recorded in high glyphosate dose under high P dose treated soils at 2 and 7 days plant back period (72.6 and 65.2 mg kg^{-1} soil in high P and high glyphosate treated soils, respectively). The lowest available P was recorded in soil applied with minimum phosphorus no glyphosate at 2 and 7 days plant back period (14.7 and 13.1 gm per kg soil respectively (Table 9b). The result indicated that glyphosate has influence on P availability which might be attributed to the competition between the two negatively charged ions for positively charged clay micelle (Cornish, 1992). Besides, the high rate of glyphosate in the soil for a prolonged period reduced the shoot biomass of wheat by unleashing its phytotoxic effect on the growth of wheat plant (Yamada and Castro, 2007).

Table 9a: Interaction effect of plant back period, phosphorus doses and glyphosate doses on yield contributing characters and yield of wheat

Treatment	Days to emergence (days)	Germination %	Leaves/plant at 15 DAS (cm)	Leaf length at 15 DAS (cm)	Plant height at 30 DAS (cm)
PBP2xHighP x NG	6.6	83.8	4.1	14.3	38.8
PBP2xHighP x RG	7.9	79.7	3.1	12.3	34.7
PBP2xHighP x HG	10.7	63.3	2.1	8.2	31.7
PBP2xMin P x NG	6.1	84.8	4.1	13.3	33.7
PBP2xMin P x RG	6.1	78.7	3.1	12.3	27.6
PBP2xMinP x HG	10.2	71.5	2.1	7.2	24.5
PBP7xHighP x NG	6.0	101.4	5.0	17.2	46.6
PBP7xHighP x RG	7.2	96.4	3.7	14.7	41.7
PBP7xHighP x HG	9.6	76.7	2.5	9.8	37.9
PBP7xMin P x NG	5.5	102.6	4.9	15.9	40.4
PBP7xMin P x RG	5.5	95.2	3.7	14.7	33.1
PBP7xMin P x HG	9.1	86.53	2.5	8.6	29.4
$LSD_{0.05}$	2.6	4.5	0.3	3.1	7.9
CV (%)	12.4	5.03	14.3	13.1	10.8

Here, High P- High Phosphorus, NG-No Glyphosate; RG-Recommended glyphosate (1.25 L ha^{-1}), HG-High Glyphosate (3.75 L ha^{-1})

Table 9b: Interaction effect of plant back period, phosphorus doses and glyphosate doses on yield contributing characters, yield of wheat and phosphorus availability in soil

Treatment	Plant height at maturity (cm)	Spike m^{-2}	Grain yield (t ha^{-1})	Available P (mg kg^{-1})	Dry weed biomass (g m^{-2})
PBP2xHighP x NG	97.6	328.9	4.7	37.2	20.2
PBP2xHighP x RG	94.9	308.4	4.5	52.5	11.7
PBP2xHighP x HG	89.9	301.3	4.1	72.6	4.2
PBP2xMin P x NG	91.9	331.9	4.2	14.7	19.4
PBP2xMin P x RG	88.8	306.4	4.3	18.9	14.9
PBP2xMinPx HG	84.8	296.2	3.9	24.2	5.2
PBP7xHighP x NG	115.3	393.9	5.7	33.4	24.3
PBP7xHighP x RG	112.8	389.9	5.4	47.1	14.0
PBP7xHighP x HG	106.8	365.6	4.9	65.2	5.1
PBP7xMin P x NG	109.2	393.9	5.1	13.1	19.4
PBP7xMin P x RG	105.6	363.6	5.1	17.0	14.9
PBP7xMinP x HG	100.7	357.4	4.6	24.2	6.3
$LSD_{0.05}$	16.8	64.8	0.8	8.6	2.3
CV (%)	9.77	10.9	9.95	14.3	10.5

PBP-Plant back period, Min P-Minimum Phosphorus (5 kg ha^{-1}), High P-High Phosphorus (30 kg ha^{-1}), NG-No glyphosate; RG-Recommended glyphosate (1.25 L ha^{-1}); HG-High Glyphosate (3.75 L ha^{-1})

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

The experiment was conducted at the research farm of Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur, Bangladesh during the period from November, 2019 to March 2020 to find out the effect of glyphosate on growth and yield of wheat (BARI Gom-26). Data on different growth parameter, yield contributing parameters, yield parameters, weed biomass and phosphorus availability were recorded and statistically analyzed. There were 12 treatments were studied in split-split-plot design with three replications. The plant back period, applying glyphosate at 2 and 7 days before sowing and phosphorus doses are the replications. The soils under two different phosphorus doses (minimum phosphorus and high dose of phosphorus) and three glyphosate doses (no glyphosate, recommended dose and high dose of glyphosate).

The growth and yield parameters of wheat, weed biomass and P concentration were varied due to the plant back period, glyphosate and phosphorus applied to the soil before crop establishment. When glyphosate applied 2 days before, days to emergence, germination and plant growth were hampered. When high glyphosate dose interacted with high P dose, the yield parameters and yield of crops were reduced. The phosphorus concentration in soil was also the highest recorded in the high glyphosate combined with high P dose. When glyphosate was applied at the recommended dose 7 days before land preparation, the yield and yield contributing characters were not that hampered when compared with high dose of glyphosate at 2 days before land preparation.

The soils under no glyphosate combined with either high P or minimum P in 2 days' plant back period had highest germination percentage, leaves/plant, leaf length at 15 DAS, plant height at 30 DAS and at maturity, spike m^{-2} and grain yield but have the highest weed biomass. However, the parameter grain yield was not significantly different among the interaction of different combinations of P doses, glyphosate doses and plant back period.

Among parameters, significant variation was found for dry weed biomass. The dry weed biomass was significantly higher in the soils where no glyphosate was applied under both the high and minimum P doses applied in soils at 7 days plant back period. The interaction of high phosphorus and no glyphosate results 20.2 g m^{-2} dry weed biomass for 2 days' plant back period and 24.2 g m^{-2} dry weed biomass for 7 days plant back period. The lowest dry weed biomass 4.2 g m^{-2} was found in the interaction of high glyphosate and high phosphorus on 2 days plant back period.

The availability of phosphorus concentration differs with the glyphosate doses and plant back period. The highest available P was recorded in the interaction of high glyphosate dose under high P dose treated soils at 2 and 7 days plant back period (72.6 and 65.2 mg kg^{-1} soil in high P and high glyphosate treated soils, respectively). The lowest available P was recorded in soil applied with minimum phosphorus no glyphosate at 2 and 7 days' plant back period (14.7 and 13.1 gm per kg soil respectively). The interaction effect of recommended phosphorus and recommended glyphosate result more available phosphorus with less difference in yield characters. The result revealed that glyphosate has influence on P availability for the competition between the two negatively charged ions for positively charged clay micelle.

The key result from the experiment was the interaction of dates of glyphosate application (plant back period), glyphosate doses, P fertilizer doses; with the high glyphosate rate and at 2 days before glyphosate application (PBP) that had a strongly negative effect on wheat phenotypic and yield contributing characters in clay loam soil where P fertilizer was also added in high dose. Otherwise, phosphorus availability increase and dry weed biomass decrease with the interaction of high phosphorus and high glyphosate dose. High P and high dose of glyphosate should be avoided to apply at a time before the initial stage of crop establishment. Recommended dose of glyphosate revealed a positive impact in the experiment. However, most of the effects were observed at the initial stage of crop growth.

CONCLUSION

- The key result from the experiment was the interaction of glyphosate, P fertilizer and plant back period.
- High glyphosate rate and high dose of P fertilizer at 2 days before glyphosate application had a negative effect on wheat phenotypic and yield in clay loam soil.
- Otherwise, phosphorus availability increase and dry weed biomass decrease with the interaction of high phosphorus and high glyphosate dose.
- Here, recommended dose of glyphosate with high phosphorus dose at 7 days plant back period revealed a positive impact in the experiment.
- High P and high dose of glyphosate should be avoided to apply at a time before the initial stage of crop establishment.
- However, most of the effects were observed at the initial stage of crop growth.

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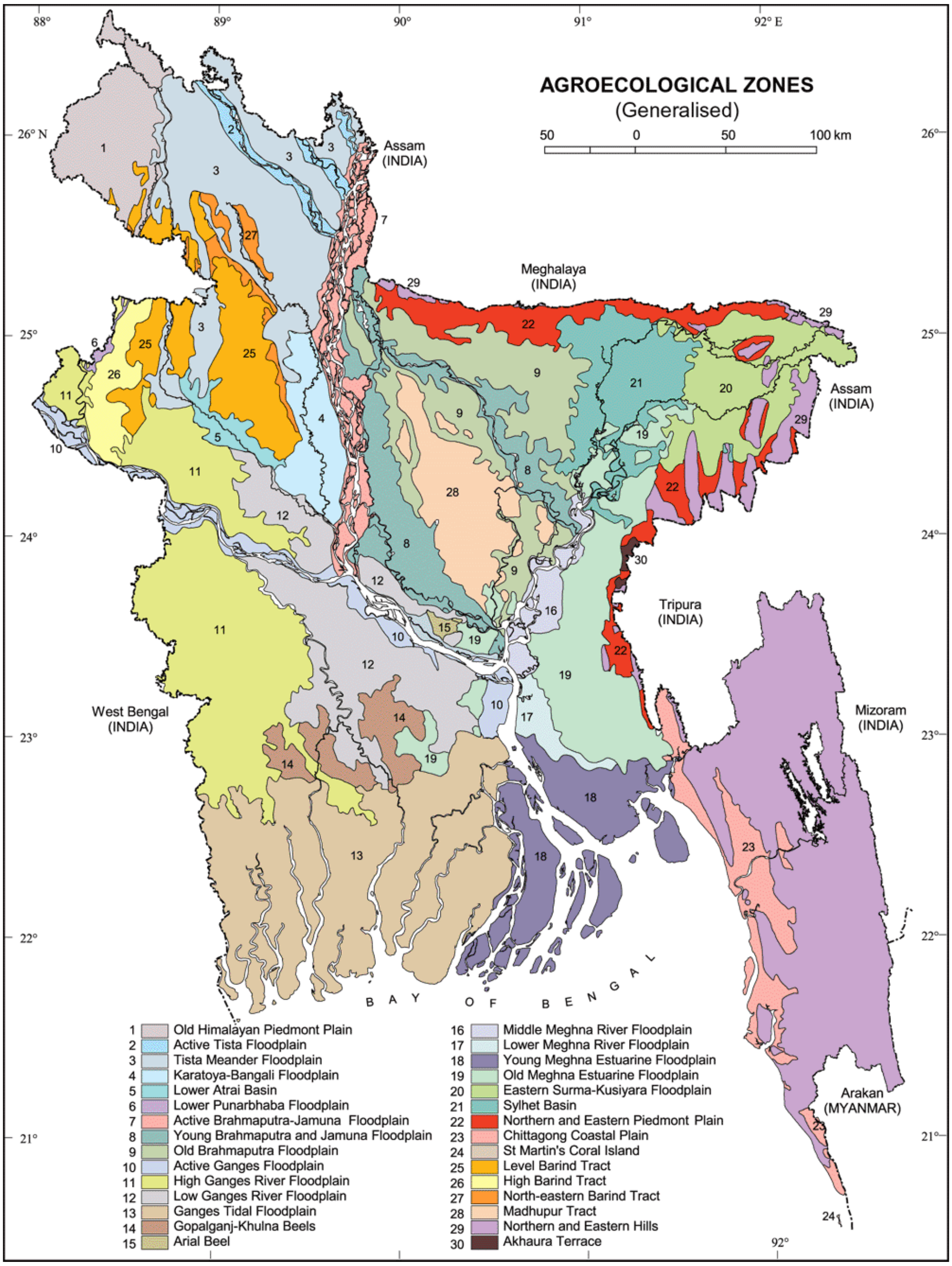
APPENDICES

Appendix I. Experimental location on the map of agro-ecological zones of Bangladesh



Appendix II. Monthly weather data during the crop growing period of the experimental site

Month	T_{max}	T_{min}	RH	Wind speed	Sunshine	Rainfall	ET_0
	(°C)		(%)	(km/h)	hour	(mm)	
*November	27.8	14.5	82	165	6.2	32	1.0
December	27.7	19.7	84	66	5.8	11	2.0
January	26.1	16.1	76	103	6.1	0	2.9
February	27.9	12.3	70	98	6.3	18	3.3
*March	32.3	19.6	69	175	7.2	43	3.7

*In November and March, only the crop growing days were considered to calculate average monthly weather components

Appendix III. Monthly weather data during the crop growing period of the experimental site

Month	T_{max}	T_{min}	RH (%)	Wind Speed (km h^{-1})	Sunshine hour	Rainfall	ET_0
	(°C)					Mm	
*December	26.6	13.8	80	59	5.9	0	2.0
January	23.9	13.1	84	86	6.5	35	2.0
February	27.3	14.6	79	107	8.8	6	2.9
March	31.2	19.9	75	168	7.2	24	4.0
*April	33.3	21.7	83	197	6.7	22	4.1

*In December and April, only the crop growing days were considered to calculate average monthly weather components

Appendix IV. Morphological and taxonomical characteristics of the Experimental site

Morphological characteristics	
	BARI, Gazipur, Bangladesh
Locality	23° 59′ 15″ NL, 90°24′ 20″, 8.80m height above the sea
Geographic position	level
AEZ	Madhupur tract (AEZ 28)
General soil type	Near neutral soil pH, Grey Terrace soils (Aeric Albaquept)
Taxonomic soil classification	
Order	Inceptisol
Suborder	Aquept
Subgroup	Aeric Albaquept
Soil series	Chhiata
Physiographic unit	Madhupur tract
Drainage	Moderate
Flood level	Above flood level
Vegetation	Clean cultivation and maintaining cropping pattern
Topography	Medium high land, 8.40m height above the sea level

Appendix V: Layout of the experimental design

HPRG 2	HPRG 7	MPRG 7	MPRG 2
HPHG 7	HPHG 2	MPHG 2	MPHG 7
HPNG 2	HPNG 7	MPNG 7	MPNG 2

Fig: Layout of experimental design
Here, Area =(3x3.15) m^2
Min P-Minimum Phosphorus (5kg/ha),
High p-High phosphorus (30 kh/ha), NG-No glyphosate; RG-Recommended glyphosate (1.25 L ha$^{-1);}$ HG- High Glyphosate (3.75 L ha^{1}).

Appendix VI: Mean square values of days to emergence and germination percentage under the experiment

Source of variation	Degree of freedom	Mean Square of	
		Days to emergence	Germination (%)
Replication (A)	2	19.6	1408.8
PBP (B)	1	57.4*	2358.8**
Phosphorus (C)	1	7.5**	81.6
Glyphosate (D)	2	51.6	1094.7
Error	16	2.3	6.7

* significant at 5% level of significance
** significant at 1% level of significance

Appendix VII: Mean square values of leaves/plant at 15 DAS, leaf length at
15 DAS, plant height at 30 DAS, plant height at maturity Under the experiment

Source of variation	Degree of freedom	Mean square of			
		Leaves/plant at 15 DAS (cm)	Leaf length at 15 DAS (cm)	Plant height at 30 DAS (cm)	Plant height at maturity (cm)
Replication (A)	2	2.4	80.4	0.14	97.1
PBP (B)	1	3.9**	44.6*	364.8	2647.8**
Phosphorus (C)	1	1.1	5.2	455.6*	319.6
Glyphosate (D)	2	15.3	147.7	247.4**	188.5*
Error	16	0.04	3.13	20.9	95.2

* significant at 5% level of significance
** significant at 1% level of significance

Appendix VIII: Mean square values of yield contributing characters spike/m^2
and grain yield (t/ha) under the experiment

Source of variation	Degree of freedom	Mean square of	
		spike/m^2	grain yield(t/ha)
Replication (A)	2	1871.9	0.41
PBP (B)	1	30452.6**	0.62*
Phosphorus (C)	1	16.7	1.1
Glyphosate (D)	2	3822.3	1.0*
Error	16	1397.5	0.22

* significant at 5% level of significance
** significant at 1% level of significance

Appendix IX: Mean square values of available phosphorus conc. (mg kg^{-1}) and dry weed biomass under the experiment

Source of variation	Degree of freedom	Mean square of	
		Available P (ppm)	Dry weed biomass (g/m^2)
Replication (A)	2	30.03	2.03
PBP (B)	1	128.6**	53.52**
Phosphorus (C)	1	9826.9**	0.9
Glyphosate (D)	2	1375.9	825.24
Error	16	24.8	1.8

* significant at 5% level of significance
** significant at 1% level of significance

SOME PICTORIAL VIEW DURING EXPERIMENTATION

Plate 1. Recommended glyphosate and high phosphorus dose

Plate 2. High glyphosate and low phosphorus injury on wheat

Plate 3. Effect of High phosphorus and no glyphosate dose on wheat growth

Plate 4. Effect of minimum phosphorus and no glyphosate on wheat growth

Plate 5. Chloroform fumigation method

Plate 6. Laboratory room (Soil Division, BARI)