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Article

Integration of Allelopathic Crop Residues and NPK Fertilizer to Mitigate Residue-Phytotoxicity, Improve Soil Fertility and Wheat Growth under Different Moisture Conditions

Integração entre Alelopatia de Resíduos de Culturas e Fertilizante NPK para Mitigar a Fitotoxicidade de Resíduos e Melhorar a Fertilidade do Solo e o Crescimento do Trigo sob Condições Diferentes de Umidade

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ABSTRACT **-** Phytotoxic effects of allelopathic crop residues are important to trickle for their use as a source of organic amendments to improve soil fertility. In present study, through pots and two year field studies, we examined the integrated effect of allelopathic residues and NPK fertilizer treatments including T_0 (control), T_1 (200-150-100 kg NPK ha^{-1}), T_2 (100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}), T_3 (100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}), T_4 (mung bean straw 8 t ha^{-1}) and T_5 (rice straw 8 t ha^{-1}) under different water regimes on soil fertility and wheat crop. Solo application of mung bean residue and rice straw caused significant inhibition of various germination and growth traits of wheat while minimal inhibition occurred when allelopathic straws were integrated with NPK fertilizer both under laboratory and field conditions, especially under 14 days of alternate wet/dry cycles. Among fertilizer treatments, mung bean residue caused a greater increase in soil organic carbon, available nitrogen and available phosphorus, while there was maximum percent increase in available potassium with T_1 (200-150-100 kg NPK ha^{-1}). Maximum increase in grain yield (30% and 33%) was achieved with T_2 (100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}) during 2014-15 and 2015-16, respectively. Integration of allelopathic crop residues with inorganic fertilizers and alternate wet/dry cycles can help to reduce the possible phytotoxic effect of allelopathic residues for sustainable wheat production.

Keywords: integrated nutrient management, organic amendments, wet dry cycles, soil properties.

RESUMO - É importante conhecer os efeitos fitotóxicos de resíduos alelopáticos de culturas para gerenciar sua utilização como fonte de corretivos orgânicos a fim de melhorar a fertilidade do solo. Na presente pesquisa, através de estudos com vasos e em campo com duração de 2 anos, examinamos o efeito integrado de tratamentos com resíduos alelopáticos e fertilizantes NPK, incluindo T_0 *(controle),* T_1 *(200-150-100 kg NPK ha*$^{-1}$*),* T_2 *(100-75-50 kg NPK ha*$^{-1}$ *+ palha de feijão-mungo 4 t ha*$^{-1}$*),* T_3 *(100-75-50 kg NPK ha*$^{-1}$ *+ palha de arroz 4 t ha*$^{-1}$*),* T_4 *(palha de feijão-mungo 8 t ha*$^{-1}$*) and* T_5 *(palha de arroz 8 t ha*$^{-1}$*) sob diferentes regimes de irrigação sobre a fertilidade do solo e a cultura do trigo. A aplicação isolada de resíduos de feijão-mungo e palha de arroz causou inibição significativa de várias características de germinação e de crescimento do trigo. Em contrapartida, ocorreu inibição mínima quando as palhas com potencial alelopático foram integradas*

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com fertilizante NPK, tanto em condições de laboratório quanto de campo, especialmente com menos de 14 dias de ciclos úmido/seco alternados. Entre os tratamentos com fertilizante, o resíduo de feijão-mungo causou maior aumento do carbono orgânico no solo, do azoto disponível e do fósforo disponível, enquanto que o aumento percentual máximo de potássio disponível foi observado com T_1 (200-150-100 kg NPK ha^{-1}). Foi observado aumento máximo na produção de grãos (30% e 33%) com T_2 (100-75-50 kg NPK ha^{-1} + palha de feijão mungo 4 t $ha^{-1)}$ durante os períodos de 2014-15 e 2015-16, respectivamente. A integração de resíduos alelopáticos com fertilizantes inorgânicos e os ciclos úmido/seco alternados pode ajudar a reduzir a possível fitotoxicidade de resíduos alelopáticos para a produção de trigo sustentável.

Palavras-chave: gestão integrada de nutrientes, corretivos orgânicos, ciclos seco-úmido, propriedades do solo.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is cultivated on more land than any other commercial crop in the world and ranks third with over 600 million tonnes annual production capacity after corn and rice (Asseng et al., 2011). It is the staple food for about 35% of the world's population and provides 50% caloric and 20% protein consumption for the poorest countries (Shiferaw et al., 2013). In Pakistan, wheat is a leading food grain crop and occupies the largest area (9.1 million ha) under a single crop. Annual production of wheat was 25.47 million tonnes in 2014-15. Wheat contributes 10% to the value added in agriculture and has a 2.1% share in Pakistan's GDP (gross domestic production) (Pakistan, 2015). It is the staple food in Pakistan and fulfills people's main dietary requirements by providing more than 55% of the calories and protein of the average diet (Khalil and Jan, 2002).

Effective nutrient management is a key factor to ensure sustainable crop production and environment safety. Among wheat yield reducing factors, low and imbalanced doses of fertilizers are some of the major causes of reduced yield of wheat (Wang et al., 2008). Thus, there is a need to apply essential nutrients, as N, P and K play a key role in green leafy growth, root growth and water balance, respectively (Havlin et al., 2005). High price, deterioration of soil physical health and environmental concerns emphasize the need for farmers to use organic sources (Aduvanshi, 2003). Balanced fertilization is the key to sustainable higher yields (Guo et al., 2009) and it can be achieved by the application of synthetic fertilizers along with organic manure, which is beneficial for the availability of primary NPK as well as some secondary and micronutrients (Bao, 1997). It will also help to sustain organic matter contents and to build soil microflora in the long run.

Addition of crop residues assists in cycling of nutrients and covers nutrient deficiencies. Use of organic sources can help to maintain nitrogen to phosphorus contents (N: P ratio) and achieve higher yield (Khanam et al., 2001; Bokhtiar et al., 2002). For poor farmers, addition of organic sources at much higher rates may not be affordable but it was found to be useful (Ahmad, 2000; Alam et al., 2000). Supply of essential nutrients is necessary for crop growth and production. Nevertheless, long term use of synthetic fertilizers results in decreasing soil productivity, environmental pollution and high costs, thus compel farmers to consider recycling of organic sources (Kiani et al., 2005). There was a positive effect on soil nutrients (N, P and K) and soil pH after the combined application of synthetic fertilizer and crop residues (Qian et al., 2008; Mousavi et al., 2012).

Slow nutrient release and decomposition of crop residues are major constraints in the use of crop residues as a nutrient source. They may influence crops negatively as a result of high C:N and allelopathic influence of crop residues on wheat (Abbas et al., 2014, 2017a). Rice and mung beans are considered to be allelopathic crops and various phytotoxic allelochemicals have been identified in these crops (Fitri et al., 2004; Berendji et al., 2008). These plant-released phytotoxins have shown strong inhibitory effects on crops, including wheat at higher doses (Abbas et al., 2014), while increase in growth occurred at reduced concentrations of these phytotoxins (Abbas et al., 2017b). In addition to the direct inhibitory effect on crops, allelopathy also influence soil properties including soil pH, nitrogen, potassium K^+, soil electrical conductivity and chloride

(Cl^-) and availability of nutrients to crops (Abbas et al., 2017a). Nitrification processes were also influenced by phenolics released from rice because of inhibition of nitrifying bacteria (Rice, 1984; Abbas et al., 2017a). According to Amb and Ahluwalia (2016), the allelopathic potential of various crops, including rice and mung bean residues, can be used to enhance nitrogen use efficiency of soil. Decomposition of crop residues is important for quick release of nutrients; however, it may release different allelochemicals that can have an inhibitory effect on soil microbes and crops (Jabran and Farooq, 2013).

One of the most appropriate ways to reduce the phytotoxic effect of crop residues is their well decomposition. Residue decomposition can be enhanced by alternate drying and rewetting events. Venterink et al. (2002) studied the significant impact of drying and rewetting cycles on nutrient availability. Soil drying increased the N mineralization and reduced denitrification than permanent wet soil, while rewetting of dried soil reduced N mineralization, increased denitrification and P extractable pool. Dry/wet cycles affect the chemical properties of soil, e.g ion equilibrium, affect the oxidation and decomposition processes which may interact with the uptake of nutrients by plants (Williams, 2009). Alternate drying and rewetting flushes are supposed to be derived from the increased mineralization of microbial biomass killed during drying and rewetting events (Miller et al., 2005; Wu and Brookes, 2005).

We hypothesized that alternate wetting and drying cycles and integration of chemical fertilizers with crop residues may help to reduce the possible phytotoxic effects of rice and mung residues on wheat crops. For this purpose, we conducted repeated laboratory and a two-year field experiments to evaluate the influence of various fertilizer and residues treatments on soil properties and wheat crops.

MATERIALS AND METHODS

Experiment 1: Integrated effect of NPK fertilizer and crop residues under different water regimes on soil fertility and wheat

To evaluate the effect of dry/wet periods and fertilizer treatments on wheat germination, early seedling growth and soil fertility, a control study was conducted at the Soil Physics Laboratory, University of Agriculture, Faisalabad, Pakistan. The laboratory temperature setting was 20 to 25 ± 2^{o}C, 14 h photoperiod and relative humidity which ranged from 28-55%. The experimental units (pots) were arranged in a completely randomized design with four replications. Pots were filled with sandy clay loam soil, which was air-dried, ground and sieved (2 mm 10 mesh^{-1}) for physico-chemical analysis of soil. The physico-chemical analysis revealed that soil type was sandy clay loam with 58, 18 and 24% of sand, silt and clay particles, respectively. Soil pH, organic matter, total nitrogen, available phosphorous and extractable potassium were 7.9, 0.86%, 0.04%, 8.82 mg kg^{-1} and 129 mg kg^{-1}, respectively. In the 1st phase of the experiment, the soil was pre-incubated at 60% of maximum water holding capacity (WHC) for 10 days at room temperature to activate the microbes. The moisture was maintained on a daily basis by weighing and adding water when needed. Crop straw (used as amendments) was dried, ground and passed through a 2 mm sieve. Six types of fertilizer treatments were applied, including T_0 (control), T_1 (200-150-100 kg NPK ha^{-1}), T_2 (100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}), T_3 (100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}), T_4 (mung bean straw 8 t ha^{-1}) and T_5 (rice straw 8 t ha^{-1}), which were mixed in soil prior to moisture treatments. Each pot was filled with experimental soil (0.35 kg) in PVC pots with 0.5 kg capacity. All the amendments were mixed uniformly. Amendments (crop straw) were applied at a rate of 1 g kg^{-1} (1% on weight basis). Different moisture treatments included 28M (28 days moist at 60% of WHC), 14M (14 days moist then 14 days dry) and 28D (28 days dry). All the pots were incubated at an average room temperature.

In 2nd phase of the experiment, which took place at 28 days after amendment and moisture treatment application, all the pots were brought at 60% water holding capacity and were maintained at this moisture level for up to 53 days. Wheat seeds were pre-soaked and eight pre-germinated seeds were sown in each pot and four plants per pot were maintained after thinning. Wheat plants were harvested after 25 days of transplanting. Soil organic carbon was measured by a K_2CrO_7-H_2SO_4 oxidation procedure. Soil C/N values were calculated as the ratio soil organic carbon to total nitrogen. Available soil inorganic N was determined as the sum of NO_3-N and NH_4-N in filtered 2 M KCl extracts (MAFF 1986). Available phosphorus was determined by the Olsen method (Olsen et al., 1954). Available potassium was measured by flame photometry after NH_4OAc neutral extraction (Richards, 1954). The repeated experiment gave statistically similar results; therefore, the pooled data were used for statistical analysis.

Experiment 2: Integrated effect of NPK fertilizer and crop residues on soil fertility and wheat production

Site description

Two-year field studies were conducted at the Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan (latitude 31°26' N and 73°06' E, altitude 185 m above mean sea level), in 2014-15 and 2015-2016. A field vacated after a rice crop was selected for this study and the physico-chemical analysis of the characteristics of the experimental soil showed the following composition: sandy clay loam (58% sand, 18% silt and 24% clay), alkaline (pH 7.9), non-saline (2.48 dS m^{-1}) and 0.86% organic matter, 0.04% total N, 8.82 mg kg^{-1}, 12 mg kg^{-1} of available phosphorus (P) and extractable potassium (K), respectively. The climate in Faisalabad has semi-arid features with mean winter rainfall and relative humidity of 10-15 pmm and 60%, respectively. In both years, meteorological data were collected from the AgroMet Observatory, Department of Agrnomy, UAF, Pakistan (Figure 1).

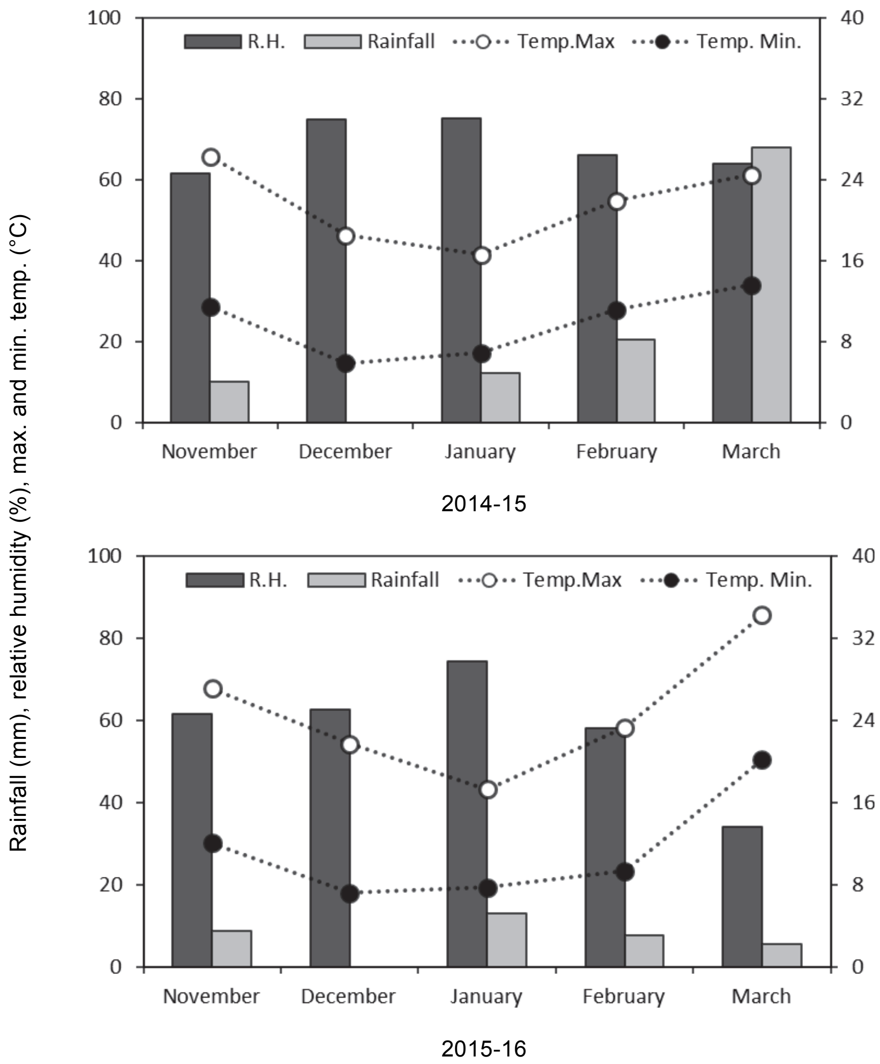


Figure 1 - Meteorological data during the course of the present study.

Experimental details

For seedbed preparation, the field was cultivated thrice with a tractor mounted plough followed by planking each time. The wheat variety (cv. Galaxy-2013) was sown at 22.5 cm row spacing with manual drill using 125 kg ha^{-1} seed rate during the third week of November. Before sowing, the seeds were soaked in water for 12 hours to promote better germination. All other agronomic practices were followed as per recommendations. Recommended fertilizer doses for the field of study were 200-150-100 kg NPK ha^{-1}. They were applied in the form of urea (46% N), diammonium phophate (46% P_2O_5 and 18% N) and sulfate of potash (50% K_2O). Based on the recommended fertilizer dose, six types of fertilizer treatments including T_0 (control), T_1 (200-150-100 kg NPK ha^{-1}), T_2 (100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}), T_3 (100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}), T_4 (mung bean straw 8 t ha^{-1}) and T_5 (rice straw 8 t ha^{-1}) were mixed in soil prior to moisture treatments. Nitrogen (N) fertilization was split into three appplications; however all doses of phosphorus (P) and potassium (K), and crop residue treatments were applied just prior to the moisture treatment. Mung bean residues and rice straw were used at 8 t ha^{-1}. Before application, mung beans and rice straw were chopped into small pieces (3-5 cm) to facilitate incorporation in the soil and decomposition. The field was kept under alternate wetting and drying (14M, which gave the best results under controlled studies) for 28 days before wheat planting. Weeds were kept under an economic threshold level by using herbicides. All other practices except those under study were kept uniform for all treatments. The crop was harvested at full maturity on 22th April, 2015 and 7th April, 2016.

Experimental design, observations and statistical analyses

The experiment was conducted under a randomized complete block design with four replications and a factorial arrangement. Data on soil organic carbon and soil available nutrients (including NPK) were collected by using same procedure described in the pot studies. Wheat grain yield was determined from each plot by harvesting the grains separately and converting the yield to t ha^{-1}.

Data for both pots and field studies were collected separately from each experimental unit and these data were subjected to Fisher's analysis of variance, and means were compared using Tukey's HSD test at the 5% probability level (Statistix 8.1, Analytical software, Statistix; Tallahassee, FL, USA, 1985-2003). Statistical analyses revealed a significant year effect; therefore, the data are described separately for both years.

RESULTS AND DISCUSSION

Seedling germination and wheat growth

Germination traits of wheat were negatively influenced by rice straw and mung bean residues. The results revealed that the solo application of rice straw caused a significant decrease in germination percentage because of its allelopathic effect. There was a more pronounced decrease in germination in T_5 (rice straw) with 28M (43%) and 28D (32%) moisture treatments. However, mean emergence of wheat seedlings was higher in T_1 (200-150-100 kg NPK ha^{-1}), which was followed by T_0 (control). Integration of rice and mung bean residues with inorganic fertilizer caused significantly less inhibition of wheat germination. Rice straw showed higher suppression of shoot and root growth of wheat seedlings (Table 1). It caused a significant decrease in shoot and root length (83-44% and 75-58%) in 28M and 28D treatment, respectively, as compared to T_1 (200-150-100 kg NPK ha^{-1}). Shoot and root biomass was significantly improved with the integrated use of crop straw and inorganic fertilizer. T_3 (100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}) showed a significant (*pd"*0.05) increase (0.45-0.99 and 0.40-0.96 g per plant) in shoot and root biomass, respectively, with 14M treatment, which was followed by T_4 (mung bean residue 8 t ha^{-1}). Among the different moisture treatments, the minimum biomass was produced in treatments with continuously wet and continuously dry conditions. The strong allelopathic potential of rice and mung bean might be the reason for germination and growth inhibition of wheat (Fitri et al., 2004; Olofsdotter, 2001). There was a lower phytotoxic effect of allelopathic

Table 1 - Effects of different fertilizer plus organic amendments on germination percentage, shoot length, root length, shoot biomass and root biomass

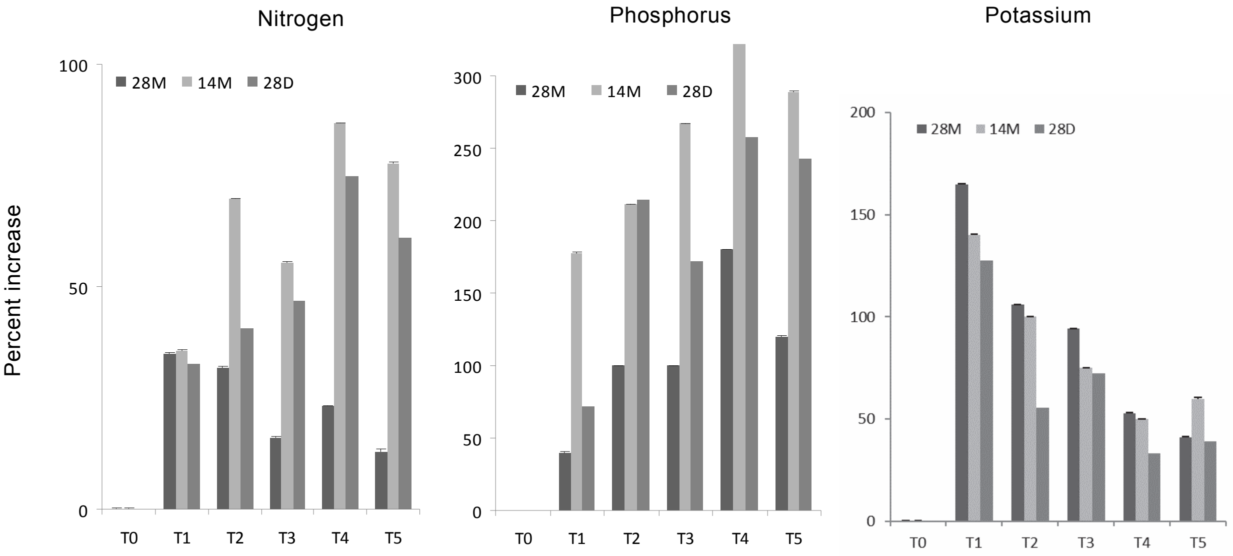
Treatment	Germination percentage (%)			Shoot length (cm)			Root length (cm)			Shoot biomass (g/plant)			Root biomass (g/plant)		
	28M	14M	28D	28M	14M	28D	28M	14M	28D	28M	14M	28D	28M	14M	28D
T_0	10±0.50a	10±0.75a	10±1.0a	27±2.50ab	27±2.75ab	28±3.0ab	33±1.75b	35±1.3b	30±1.25ab	0.2±0.12e	0.45± 0.13e	0.38 ± 0.45ef	0.38±0.20e	0.40±0.35e	0.40± 0.45e
T_1	100±1.80a	10±1.33a	10±0.77a	33±6.30a	34±4.75a	35±5.0a	36±4.89ab	40±5.75a	38±3.15a	0.86±0.5a-c	0.85±0.35a-c	0.77 ± 0.23a-f	0.80±0.24b	0.86±0.40ab	0.80 ± 0.23b
T_2	90±0.65b	10±0.90a	93±1.5b	30±6.0ab	34±5.5a	33±4.0a	31±5.0b	34±4.85b	30±4.0bc	0.85±0.4a-c	0.90±0.15ab	0.80 ± 0.6bc	0.75±0.55c	0.85±0.30b	0.74 ± 0.6c
T_3	85±1.65bc	95±1.35ab	87±1.28b	28±2.80ab	32±3.75b-d	26±4.25b	28±3.75bc	35±4.15b	30±3.25bc	0.75± 0.34c	0.99±0.4a	0.76 ± 0.39b-f	0.80±0.62b	0.96±0.50a	0.74 ± 0.39c
T_4	78±1.05c	90±0.80b	85±1.75bc	25±3.35b	30±4.75a	26±5.25b	24±4.5c	34±3.85b	25±4.75c	0.72±0.13c	0.95±0.15 a	0.63 ± 0.19c	0.68±0.48c	0.90±0.65a	0.68 ± 0.19c
T_5	70±1.38d	92±1.48ab	76±1.62c	18±4.15c	28±5.15ab	2±5.75c	20±5.25cd	33±5.5b	24±4.85c	0.65 ± 0.32d	0.93 ± 0.39 ab	0.65 ± 0.48d	0.67±0.48c	0.87±0.58ab	0.60 ± 0.48d

T_0: control, T_1: 200-15-100 kg NPK ha^{-1}, T_2: 100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}, T_3: 100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}, T_4: mung bean straw 8 t ha^{-1} and T_5: Rice straw 8 t ha^{-1}. 28M: 28 days moist at 60% of WHC, 14M: 14 days moist then 14 days dry and 28D: 28 days dry. The means within the same column with the same letter are not differed significantly at the 5% confidence level. The data are the means ± standard error.

residues, and the higher shoot growth in the pots treated with both residues and inorganic fertilizer along with different wet and dry cycles was due to quick decomposition of plant residues (Moran et al., 2005) and release of nutrients (Venterink et al., 2002). According to Misra and Tyler (2000), drying and wetting events have a significant effect on root and shoot biomass as compared to the continuously drying or the continuously wet treatment. The increase in wheat yield was due to contribution of growth and yield contributing parameters.

Soil available NPK and soil organic carbon content

Different fertilizer treatments and wet/dry cycles significantly increased the availability of N, P and K. Alternate wetting and drying events caused a higher percent increase in N, P and K as compared to constantly wet (28M) and dry conditions (28D). There were 86% and 77% increases in available N in T_4 (mung bean 8 t ha^{-1}) and T_5 (rice straw 8 t ha^{-1}), respectively, as compared to control at 14M. The same treatments caused maximum increase (344% and 288%) in available P, respectively. However, maximum concentration (41-48 mg kg^{-1}) of available K was achieved in pots treated with T_1 (200-150-100 kg NPK ha^{1}) along with the 14M treatment (Figure 2). The results of current studies are in agreement with the studies of Huang et al. (2010), who estimated high nutrient concentrations (NP) after the addition of crop residues. The release of high nitrogen content from mung bean straw has been reported by Kamkar et al. (2014).

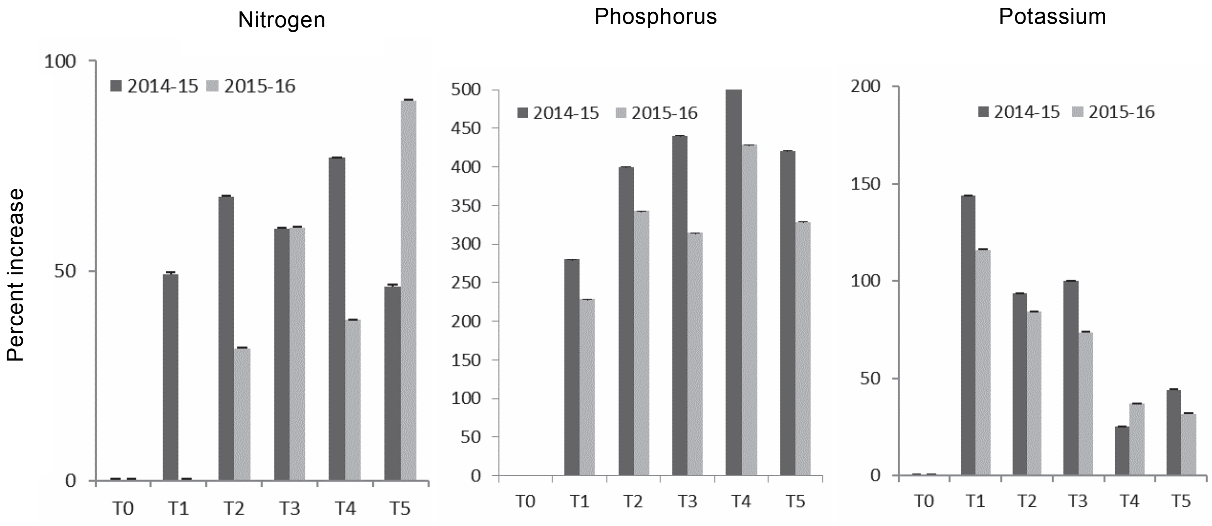


T_0: control, T_1: 200-15-100 kg NPK ha^{-1}, T_2: 100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}, T_3: 100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}, T_4: mung bean straw 8 t ha^{-1} and T_5: Rice straw 8 t ha^{-1}. 28M: 28 days moist at 60% of WHC, 14M: 14 days moist then 14 days dry and 28D: 28 days dry.

Figure 2 - Integrated effect of treatments with fertilizer plus organic amendments on percent increase in available nitrogen, phosphorus and potassium.

Different fertilizers plus organic amendment treatments caused a significant increase in soil available nitrogen, phosphorus and potassium contents during both years of study (2014-15 and 2015-16). Application of mung bean residues at 8 t ha^{-1} (T$_4$) showed maximum increase in N (up to 85%) and P (up to 490%) as compared to all other treatments while there was a higher percent increase in K (up to 145%) content in T$_1$ (200-150-100 kg NPK ha^{-1}) in both years of study (Figure 3). A significant interactive effect of fertilizer treatments revealed that there was maximum increase in soil organic carbon contents in plots treated with sole mung bean residues at 8 t ha^{-1} (T$_4$), followed by the rice straw 8 t ha^{-1} (T$_5$) treatment in both years of study (2014-15 and 2015-16) (Table 2). Among fertilizer treatments, minimum organic carbon contents (0.98-1.02 g kg^{-1}) were found in the sole application of NPK, followed by T$_2$ and T$_3$ (Figure 3). Similarly, Li et al. (2006) also found high N and P contents in treatments with integrated application of NPK and crop residues. Turner and Haygarth (2001) established the fact that wetting and drying events cause quick release of nutrients from the soil by influencing soil microbial biomass. However, K contents were higher in the recommended NPK treatment, followed by T$_2$ (100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}) and T$_3$ (100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}), which correlates with the studies of Dong et al. (2012). Low NPK contents were found in the 28D (continuous drying) and 28M (continuous wetting) treatments, which correlates with the studies of Kramer and Green (2000), who reported that continuous drying reduces the nutrient mineralization rate. There was maximum increase (175%) in soil organic carbon contents in pots treated with sole mung bean residues at 8 t ha^{-1} (T$_4$) along with alternate duration of wetting and drying at 14 days interval (14M) as compared to control (Table 4). It was followed by rice straw at 8 t ha^{-1} (T$_5$) with the same moisture treatment. Minimum soil organic carbon contents were found in control, which was followed by T$_1$ (200-150-100 kg NPK ha^{-1}) (Table 3).

Agricultural practices (including use of organic matter) play an important role in regulating nutrient contents in field soils (Tong et al., 2009). Thus, it is a key factor in maintaining soil fertility (Huang et al., 2010). Significantly higher organic carbon contents were found in treatments with crop residue along with carbon emission, which might be derived from the lysis of microbial cells as a result of an osmotic shock on rewetting of dry soil (Kieft et al., 1987; Fierer and Schimel, 2003). It is in accordance with the findings of Turner and Haygarth (2001), who established the fact that there is a rapid release of nutrients after drying and rewetting of soil. Soil drying exposes new soil surfaces after disruption of aggregates and further disruption of these surfaces by swelling as a result of rewetting and ultimately release of nutrients (Ouyang and Li, 2013).



The bar indicates the standard error.

T$_0$: control, T$_1$: 200-15-100 kg NPK ha^{-1}, T$_2$: 100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}, T$_3$: 100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}, T$_4$: mung bean straw 8 t ha^{-1} and T$_5$: Rice straw 8 t ha^{-1}. 28M: 28 days moist at 60% of WHC, 14M: 14 days moist then 14 days dry and 28D: 28 days dry.

Figure 3 - Integrated effect of treatments with fertilizer plus organic amendments on percent increase in available nitrogen, phosphorus and potassium in 2014-15 and 2015-16.

Table 2 **-** Effects of different treatments with fertilizer plus organic amendments on soil organic carbon

Treatment	Soil organic carbon (%)	
	2014-15	2015-16
T_0	0.75 ± 0.15f	0.81 ± 0.75d
T_1	0.98 ± 0.19e	1.02 ± 0.98d
T_2	1.48 ± 1.12c	1.47 ± 1.14c
T_3	1.21 ± 0.99d	1.63 ± 1.25bc
T_4	1.85 ± 0.87a	2.17 ± 1.52a
T_5	1.64 ± 0.65b	1.85 ± 1.11b

T_0: control, T_1: 200-15-100 kg NPK ha^{-1}, T_2: 100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}, T_3: 100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}, T_4: mung bean straw 8 t ha^{-1} and T_5: Rice straw 8 t ha^{-1}. 28M: 28 days moist at 60% of WHC, 14M: 14 days moist then 14 days dry and 28D: 28 days dry. The means within the same column with the same letter are not differed significantly at the 5% confidence level. The data are the means ± standard error.

Table 3 - Effects of different treatments with fertilizer plus organic amendments on soil organic carbon content

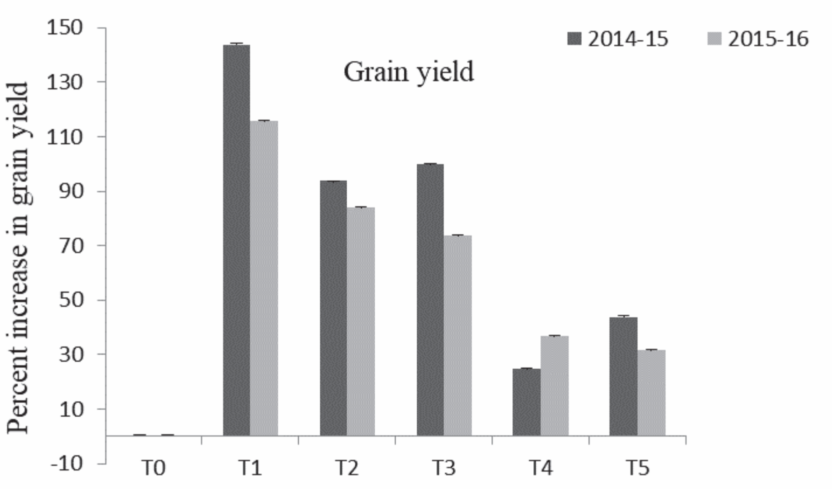
Treatment	Soil organic carbon (%)		
	28M	14M	28D
T_0	0.75 ± 0.87 e-f	0.76 ±0.95 def	0.66 ± 0.082 f
T_1	1.14 ±0.14 b-f	1.21 ±0.15 b-e	1.02 ± 0.13 c-f
T_2	1.08 ±0.14 c-f	1.28 ±0.16 b-e	1.05 ±0.13 c-f
T_3	1.21±0.15 b-f	1.31 ±0.16 b-d	1.14 ±0.14 b-f
T_4	1.63 ±0.20 ab	2.09 ±0.26 a	1.44 ±0.18 bc
T_5	1.52 ±0.19 bc	1.67 ±0.20 ab	1.37 ±0.17 bc

T_0: control, T_1: 200-15-100 kg NPK ha^{-1}, T_2: 100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}, T_3: 100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}, T_4: mung bean straw 8 t ha^{-1} and T_5: Rice straw 8 t ha^{-1}. 28M: 28 days moist at 60% of WHC, 14M: 14 days moist then 14 days dry and 28D: 28 days dry. The means within the same column with the same letter are not differed significantly at the 5% confidence level. The data are the means ± standard error.

Total biomass production was found to be higher in the DM treatment as compared to constantly dry or wet treatments.

Growth and yield of wheat

A significant interactive effect of fertilizer treatments revealed that maximum increase (18.5-25%) in plant height occurred in plots treated with T_2 (100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}), followed by T_3 (100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}) in both years of study (Table 4). The highest 1000 grain weight (5-7%) was found in the plots treated with T_1 (200-150-100 kg NPK ha^{-1}), followed by T_2 (100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}) and T_3 (100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}) treatments in both years of study (2014-15 and 2015-16) (Table 4). The numerically highest (22.5-22.7%) dry biomass was found in T_1 (100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}) in both years of study (2014-15 and 2015-16) while T_2 (100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha ^{1}), T_3 (100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}), T_4 (mung bean straw 8 t ha^{-1}) and T_5 (rice straw 8 t ha^{-1}) were not significantly different from one another. The lowest dry biomass was found in T_0 (control), but it was statistically insignificant (Table 4). There was a percent increase in wheat grain yield in T_3 (100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}) and T_4 (mung bean straw 8 t ha^{-1}) (Figure 4). Addition of crop residues significantly increase wheat grain yield (Mohammad et al., 2012) as a result of the increase in organic matter content (Heen and Chan, 1992; Dalal and Chan, 2001; Lal et al., 2003), which is a source of nutrients (Chan et al., 2008). Because of high C:N ratio, rice straw may cause N immobilization but the combined use of organic residues and mineral fertilizers enhanced crop N synchrony and reduced N losses (Gentile et al., 2009). The combined use of mineral fertilizer and crop residue has the potential to make the nutrients more available for plant uptake (Gentile et al., 2008).



The bar indicates the standard error.

T_0: no fertilizer; T_1: recommended NPK; T_2: ½ recommended rate of NPK + Mung bean; T_3: ½ recommended rate of NPK + rice straw; T_4: mung bean straw and T_5: Rice straw.

Figure 4- Integrated effects of different treatments with fertilizer plus organic amendments on percent increase in grain yield of wheat.

Table 4 - Effects of different treatments with fertilizer plus organic amendments on plant height, 1000 grain weight and dry biomass

Treatment	Plant height (cm)		1000 grain weight (g)		Dry biomass (g m^{-2})	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
T_0	84.5 ± 4.32c	83.0 ± 3.75c	40.25 ± 4.31b	39.89 ± 3.84c	10.11 ± 1.84c	10.31 ± 1.52c
T_1	95.9 ± 3.76ab	93.8 ± 4.21ab	42.22 ± 4.20a	42.72 ± 4.21a	12.39 ± 2.12a	12.65 ± 2.45a
T_2	100.1 ± 4.23a	104.5 ± 4.1a	42.04 ± 3.89a	41.84 ± 4.1ab	11.43 ± 1.92b	11.71 ± 1.93b
T_3	97.1 ± 2.65a	96.3 ± 3.89ab	42.10 ± 4.22a	41.84 ± 3.90ab	11.25 ± 1.81b	11.77 ± 1.86b
T_4	95.8 ± 3.21ab	93.8 ± 3.98ab	41.89 ± 3.85a	41.47 ± 4.10b	10.92 ± 1.75b	11.35 ± 1.79b
T_5	93.8 ± 3.98b	87.2 ± 3.87b	41.78 ± 3.92a	41.38 ± 3.97b	10.99 ± 1.82b	11.49 ± 2.25b

T_0: control, T_1: 200-15-100 kg NPK ha^{-1}, T_2: 100-75-50 kg NPK ha^{-1} + mung bean straw 4 t ha^{-1}, T_3: 100-75-50 kg NPK ha^{-1} + rice straw 4 t ha^{-1}, T_4: mung bean straw 8 t ha^{-1} and T_5: Rice straw 8 t ha^{-1}. 28M: 28 days moist at 60% of WHC, 14M: 14 days moist then 14 days dry and 28D: 28 days dry. The means within the same column with the same letter are not differed significantly at the 5% confidence level. The data are the means ± standard error.

Source: AgroMet Observatory, Department of Crop Physiology, UAF.

In conclusion, integration of inorganic fertilizers with allelopathic crops (mung bean and ricee) residues helped to mitigate their phytotoxic effects on wheat, especially under alternate wet dry cycles. In addition, it also improves soil fertility and wheat yield.

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