Research Article

Optimizing surface soil NPK balance through integrated nutrient management in wheat-soybean cropping system from Rawalakot Pakistan

Abdul Khaliq1, Mohsin Zafar1*, Muhammad Kaleem Abbasi1, Majid Mahmood Tahir1 and Sair Sarwar2

1. Department of Soil and Environmental Sciences, University of the Poonch Rawalakot, Azad Jammu and Kashmir-Pakistan
2. Land Resources Research Institute (LRRI) National Agricultural Research Centre (NARC) Islamabad-Pakistan

*Corresponding author’s email: mohsinses@gmail.com

Citation

Abstract
The efficient use of organic-inorganic amendments and changing cropping pattern are important management strategies to improve crop productivity as well as restore the nutrient buildup of degraded soils. A three-year (2008–09 to 2010–11) soybean-wheat rotation field experiment was conducted at Rawalakot, Azad Jammu and Kashmir. Treatments included PM100, WSR100, PM50+WSR50, UN100, UN50+PM50, UN50+WSR50, UN50+PM25+WSR25 and a control (unfertilized). Applications of amendments were made on N-equivalent basis at the rate of 100 kg N ha−1. Data on surface NPK balance showed a net depletion of 41.2 kg N ha−1 year−1 and gain of 95.8 and 16.5 kg ha−1year−1 of phosphorus (P) and potassium (K) for the control soil during three years. Soil amended with either organic amendments (PM and WSR) and UN alone or combination of both organic amendments + UN yielded positive surface N and P balance that varied between 40.7-86.8 and 84.5-213.7 kg ha−1year−1, respectively under different amendments. The UN100 and UN50+PM50 treatments showed a K deficit of 12 and17.1 kg ha−1year−1, respectively while UN50+WSR50 and UN50+PM25+WSR25 treatments marginally increased soil K content between 1.3-5.2 kg ha−1year−1compared to 16.5 kg ha−1year−1 in the control treatment. Treatments receiving repeated applications of poultry manure alone or with UN has the potential to improve the surface N and P balances. Therefore, it is recommended to increase annual addition of K fertilizer (beyond 50 kg K2O ha−1year−1) with organic-inorganic amendments to maintain K balance and sustain long-term soybean-wheat productivity of degraded soils of Himalayan Hindukush of Azad Jammu and Kashmir.

Keywords: Integrated fertilization; Nutrient balance; Surface soil; Wheat straw residue

Introduction
Plant nutrient budgeting is a system of gross evaluations of sustainability of agro-ecosystems that monitors nutrient flows to and from fields (nutrient inputs and outputs), determines yield levels and evaluates soil
health and quality. Nutrient budget analyses are also of particular importance in addressing the environmental problems associated with nutrient accumulations/depositions from excessive applications of organic manures and can serve as useful devices to both general public and policymakers [1]. Calculations for nutrient budgets on a variety of scales (from plot and catchment to continental scales) provide information regarding the present nutrient status and dynamics of soil fertility. The introduction of high yield potential cultivars of crops, increased cropping intensity, greater erosion and lack of nutrient inputs from either organic or manufactured nutrient sources commonly contributed to the nutrients mining, fertility depletion and negative nutrient balances in soil [2]. In addition, nutrient uptake pattern of different crops provides a fair estimate of the crop demands for the specific nutrients and the extent to which mining of the soil nutrient might be critical for optimizing crop productivity. Numerous long-term field studies [3] conducted in Asian region on yield and fertility evaluation had shown that elevated nutrient deficiencies, low soil organic matter, nominal use of animal manures and other organic nutrient sources and inappropriate/imbalanced nutrient management are mainly attributed to the fertility depletion with the consequent reduction in yields.

Supplementing the nutrients particularly N from manufactured fertilizers is not sufficient to restore long term soil fertility and to maintain nutrient balance because of significant unwanted losses of applied nutrients. Mismanagement of N fertilizer causes economic losses, environmental degradation and gaseous emissions that adversely affect the sustainability of crop productivity. [4] estimated that more than 50% of total applied N fertilizer from agricultural systems is volatilized into the atmosphere or washed into water reservoirs via leaching, runoff and erosion causing environmental pollution and annual economic loss of about US$ 17 billion. In addition, there are some other reports that continuous use of excessive mineral N fertilizers gradually declines soil organic matter level, increases soil acidity, causes micronutrient deficiencies and accelerates land and environmental degradation [5].

Organic manures particularly poultry manure (PM) and crop residues are the other important nutrient sources that add substantial amounts of nutrients through mineralization into the mineral pool of soil and play an important role in sustaining crop productivity [6]. In conventional farming systems, the repeated application of PM is thought to be more effective and superior than chemical fertilizers for improving the yield of some agricultural crops because of balanced nutrients supply and its longer persistence in soil [7]. Similarly, [8] documented that the application of organic manures as soil amendment increases the availability of nutrients because of nutrients release in soil from native pool as well as their long lasting residual effects. In addition, numerous previous studies [9] had revealed that besides containing 2.5 to 3.0% total N, PM has the potential to supply considerable amounts of P, K and some of the micronutrients and its long-term utilization sustains soil fertility and productivity.

Both the manures and chemical fertilizers alone cannot sustain long-term productivity of the traditionally grown maize and wheat crops in Azad Jammu and Kashmir, therefore, ecological acceptable and practically feasible crop-soil nutrient management approaches like integrated nutrient management (INM) and introduction of legume-based cropping system such as soybean-wheat rotation need urgent attentions for improving nutrients availability and sustaining long-term crop productivity. The judicious combination of organic-
inorganic nutrient sources maintains soil health, crop productivity, augments efficiency of added nutrients (synergistic effect), improves soil physical conditions and results in better utilization of both water and nutrients from the soil [10]. The integrated management of nutrients results in sustainable crop production, build-up of total soil carbon pool, improves the level of major soil nutrients especially nitrogen and phosphorus and reduces the risk of environmental pollution [11]. The legume-based rotation of cereals is also an important component of profitable cropping systems because legumes fix substantial amounts of atmospheric N\textsubscript{2} and represent a renewable source of N for agriculture. In addition, soil incorporation of legume residues, roots and senesced nodules adds 25 % of their N through mineralization for subsequent cereal crop and improves organic matter level of the soil [12].

The objective of this study was to evaluate the short-term changes in nutrient balances of soil supplemented with organic-inorganic amendments in wheat- soybean cropping system.

Materials and methods
Description of experimental site
The study site was located in an experimental farm of University of the Poonch Rawalakot, Azad Jammu and Kashmir, in the north–east of Pakistan under the foothills of great Himalayas. The area lies between the altitude of 1800–2000 m above sea level and latitude 33 – 36\textdegree. The topography is mainly hilly and mountainous with valleys and stretches of plains. The area is characterized by a temperate sub-humid climate with annual average rainfall ranging from about 500–2000 mm, most of which is irregular and falls with intense storms during monsoon and winter. Mean annual temperature is about 28 \degree C (maximum) in summer while winter is fairly cold with temperature ranging even below freezing point. The monthly precipitation and temperature of the experimental area during the investigation years (2008-09, 2009-10, and 2010-11) are presented in (Table 1). A series of field experiments was carried-out during three consecutive years on loam (Thermic Lithic Eutru-depts) soil, developed from the colluvial parent materials.

Experimental details
Before the onset of the experiment and for proper field bed preparation, the field was plowed 2-3 times to a depth of about twenty cm and left as such for the next two weeks. The treatments were comprised of all combinations of three sources of N a) organic N sources i) animal origin i.e. poultry manure (PM) ii) plant origin i.e. wheat straw residues (WSR) b) mineral N as urea (UN) and a control (no N). These amendments were applied alone or integrated with different combinations. Altogether, a total of eight treatments were used. Nitrogen from different treatments was applied at the rate of 100 kg N ha\textsuperscript{-1} generally recommended as optimum N rate for wheat and soybean under environmental conditions of the region. The N rates from PM and WSR were calculated on the basis of total N content in both the organic sources i.e. 2.57 %, and 0.91 %, respectively (Table 2).
Table 1. Meteorological data i.e. total rainfall and minimum and maximum temperature of the experimental site Rawalakot for three years (2009, 2010 and 2011)

<table>
<thead>
<tr>
<th>Months of year</th>
<th>Total rainfall (mm)</th>
<th>Min. Temp. (°C)</th>
<th>Max. Temp. (°C)</th>
<th>Total rainfall (mm)</th>
<th>Min. Temp. (°C)</th>
<th>Max. Temp. (°C)</th>
<th>Total rainfall (mm)</th>
<th>Min. Temp. (°C)</th>
<th>Max. Temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year 2009</td>
<td>Year 2010</td>
<td>Year 2011</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>103.2</td>
<td>-0.8</td>
<td>12.8</td>
<td>38.5</td>
<td>-1.3</td>
<td>15.6</td>
<td>20.0</td>
<td>-3.5</td>
<td>12.1</td>
</tr>
<tr>
<td>February</td>
<td>148</td>
<td>0</td>
<td>12.9</td>
<td>295.2</td>
<td>0.1</td>
<td>11.9</td>
<td>328</td>
<td>-0.2</td>
<td>11.1</td>
</tr>
<tr>
<td>March</td>
<td>145</td>
<td>3.2</td>
<td>17.9</td>
<td>83.2</td>
<td>5.2</td>
<td>21.7</td>
<td>164.6</td>
<td>3.2</td>
<td>18.2</td>
</tr>
<tr>
<td>April</td>
<td>200</td>
<td>5.9</td>
<td>21.8</td>
<td>44.9</td>
<td>7.7</td>
<td>25.0</td>
<td>231.1</td>
<td>6.0</td>
<td>20.0</td>
</tr>
<tr>
<td>May</td>
<td>41</td>
<td>9.9</td>
<td>27.5</td>
<td>135</td>
<td>10.2</td>
<td>26.0</td>
<td>27.5</td>
<td>12.1</td>
<td>28.0</td>
</tr>
<tr>
<td>June</td>
<td>160</td>
<td>11.4</td>
<td>28.2</td>
<td>59.1</td>
<td>12</td>
<td>27.3</td>
<td>112.6</td>
<td>15</td>
<td>28.3</td>
</tr>
<tr>
<td>July</td>
<td>217.6</td>
<td>15.3</td>
<td>28.6</td>
<td>256.1</td>
<td>16.1</td>
<td>26.5</td>
<td>217.3</td>
<td>16.4</td>
<td>25.8</td>
</tr>
<tr>
<td>August</td>
<td>167</td>
<td>16.4</td>
<td>27.4</td>
<td>169.9</td>
<td>17.2</td>
<td>25.4</td>
<td>258.7</td>
<td>17.2</td>
<td>25.6</td>
</tr>
<tr>
<td>September</td>
<td>81.5</td>
<td>11.7</td>
<td>27.2</td>
<td>25.9</td>
<td>13.9</td>
<td>26.2</td>
<td>167.3</td>
<td>14.4</td>
<td>25.7</td>
</tr>
<tr>
<td>October</td>
<td>29</td>
<td>5.3</td>
<td>23.3</td>
<td>78.9</td>
<td>7.0</td>
<td>23.5</td>
<td>25.7</td>
<td>7.1</td>
<td>23.2</td>
</tr>
<tr>
<td>November</td>
<td>39</td>
<td>1.0</td>
<td>18.7</td>
<td>2.0</td>
<td>2.6</td>
<td>20.9</td>
<td>11.3</td>
<td>2.5</td>
<td>20.4</td>
</tr>
<tr>
<td>December</td>
<td>39.3</td>
<td>-0.8</td>
<td>14.9</td>
<td>28.1</td>
<td>-1.9</td>
<td>16.1</td>
<td>12.3</td>
<td>-1.8</td>
<td>15.5</td>
</tr>
</tbody>
</table>

Source: The Directorate, Regional Meteorological centre, 46 Jail Road, Lahore, Pakistan

Table 2. The detail of treatment combinations is described in the below given

<table>
<thead>
<tr>
<th>Treatment Symbol</th>
<th>Treatment Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;sub&gt;1&lt;/sub&gt;</td>
<td>control without any amendment (check)</td>
</tr>
<tr>
<td>T&lt;sub&gt;2&lt;/sub&gt;</td>
<td>poultry manure (PM, equivalent to 100 kg N ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
</tr>
<tr>
<td>T&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Wheat straw residues (WSR, equivalent to 100 kg N ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
</tr>
<tr>
<td>T&lt;sub&gt;4&lt;/sub&gt;</td>
<td>urea nitrogen (UN equivalent to 100 kg N ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
</tr>
<tr>
<td>T&lt;sub&gt;5&lt;/sub&gt;</td>
<td>PM+WSR (50: 50)</td>
</tr>
<tr>
<td>T&lt;sub&gt;6&lt;/sub&gt;</td>
<td>UN+PM (50:50)</td>
</tr>
<tr>
<td>T&lt;sub&gt;7&lt;/sub&gt;</td>
<td>UN+WSR (50: 50)</td>
</tr>
<tr>
<td>T&lt;sub&gt;8&lt;/sub&gt;</td>
<td>UN+ PM+ WSR (50: 25: 25)</td>
</tr>
</tbody>
</table>

The treatments were assigned to the respective plots according to randomized complete block design (RCBD) with three replications. The net plot size was 3m×2m (6m<sup>2</sup> plot area). The time of sowing was selected on the basis of sowing time of a particular crop and availability of proper moisture in the field (depending upon the rainfall).

Well-rotten PM and dried WSR were broadcasted and well incorporated into the soil before the sowing of each crop for three consecutive cropping (wheat-soybean) cycles. In case of wheat, urea N was applied in two equal splits i.e. half dose at sowing and the remaining half at tillering while for soybean crop the urea N was splitted into three doses i.e. 50 kg N ha<sup>-1</sup> at sowing and the remaining 50 kg N in further two equal splits (i.e. 25 kg N ha<sup>-1</sup> at flowering and 25 kg N ha<sup>-1</sup> at pod filling stages). In integrated N treatments, application of UN was also done in two or three splits accordingly. The same treatments were manually repeated for the
subsequent years. The basal doses of phosphorus and potassium from single super phosphate (SSP) and sulfate of potash (SOP) were applied at the rate of 50 kg P2O5 and K2O (each) to all plots including control at sowing of each crop in all the three years of experimentation. All the fertilizers were well mixed into the soil. Wheat (*Triticum aestivum L*) variety shafaq-2006 (at the rate of 120 kg seed ha⁻¹) and soybean variety NARC-1 (at rate of 80 to 100 kg seed ha⁻¹) were used as testing crops. All standard local cultural practices were followed when required throughout the growth period. No irrigation was provided, and manual weeding was carried out as per requirement (Table 3).

**Table 3. Physio-chemical characteristics of Rawalakot soil and chemical composition of organic amendments used for field experimentation**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Unit</th>
<th>Depth (cm)</th>
<th>Properties</th>
<th>unit</th>
<th>Poultry manure (PM)</th>
<th>Wheat straw Residues (WSR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0-15</td>
<td>16-30</td>
<td>Mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk density</td>
<td>g cm⁻³</td>
<td>1.36</td>
<td>1.48</td>
<td>1.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>g kg⁻¹</td>
<td>434.0</td>
<td>427.0</td>
<td>426.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silt</td>
<td>g kg⁻¹</td>
<td>326.0</td>
<td>343.0</td>
<td>304.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>g kg⁻¹</td>
<td>240.0</td>
<td>230.0</td>
<td>270.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Textural class</td>
<td>-----</td>
<td>Loam</td>
<td>C/N ratio</td>
<td>-----</td>
<td>13.6</td>
<td>45.9</td>
</tr>
<tr>
<td>Soil pH (1:2 H₂O)</td>
<td>-----</td>
<td>6.89</td>
<td>7.01</td>
<td>6.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic matter</td>
<td>g kg⁻¹</td>
<td>10.3</td>
<td>8.92</td>
<td>7.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total N</td>
<td>g kg⁻¹</td>
<td>0.53</td>
<td>0.45</td>
<td>0.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Available P</td>
<td>mg kg⁻¹</td>
<td>5.49</td>
<td>5.12</td>
<td>5.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extractable K</td>
<td>mg kg⁻¹</td>
<td>98.5</td>
<td>87.8</td>
<td>93.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>mg kg⁻¹</td>
<td>17.8</td>
<td>7.36</td>
<td>12.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>mg kg⁻¹</td>
<td>6.2</td>
<td>4.0</td>
<td>5.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>mg kg⁻¹</td>
<td>8.4</td>
<td>3.9</td>
<td>6.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>mg kg⁻¹</td>
<td>3.79</td>
<td>0.82</td>
<td>2.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cation exchange capacity</td>
<td>cmol(+) kg⁻¹ soil</td>
<td>11.9</td>
<td>10.6</td>
<td>11.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyphenol</td>
<td>g kg⁻¹</td>
<td>208.7</td>
<td>43.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Biochemical analysis of plant and grain samples**

Plant and grain samples of both wheat and soybean crops were dried in an air forced oven at 65 °C for about 48 hours, ground in a Wiley mill (Polymix PX-MFC 90D; Switzerland) to pass through a 1-mm sieve. Total N in ground plant material was estimated by Kjeldhal digestion, distillation and titration methods [13]. Total P and K were measured by digesting 0.25 g of material with sulfuric acid and hydrogen
peroxide. The P in the digests was measured by colorimetry by using P standards of potassium dihydrogen phosphate [14] and K was determined by atomic absorption spectrophotometer [15]. Total N-P-K plant uptake was calculated from dry matter (DM) accumulation and NPK concentration in shoot of wheat and soybean.

Grain samples of wheat and soybean were also analyzed for N, P and K concentrations using the procedures described for plant analysis and (wheat and soybean) N-P-K uptake was calculated by multiplying grain N-P-K concentrations to their respective grain yields [16].

**Nutrient input and output measurements and interpretations**

The partial surface balancing of N, P and K in wheat-soybean cropping system mainly based on four inputs i.e. mineral fertilizer, organic manures, crop residues and biological N2-fixation and sedimentations; and five outputs, i.e. nutrients removal in harvested grain products, removal by residues, leaching, gaseous losses and water erosion. Of these factors, we carried out the measurements of nutrients applications through mineral fertilizers, organic manures, crop residues recycling, biological N2-fixation and rain water; and nutrients removal with harvested crop products and crop residues. The leaching, gaseous and water erosion losses of nutrients were not directly measured due to certain technical and practical constraints. However, the leaching losses of N and K were estimated with the help of following regression model [17].

N Leaching= (0.0463+0.0037) × (P/(C×L))) × (F+D×NOM-U)

K Leaching= -6.87+0.0117×P+0.173×F-0.265×CEC

Where

P = Annual precipitation (mm), C = percentage of clay (%), L = Layer thickness/rooting depth (m), F = Mineral and organic fertilizer nitrogen applied (kg N ha⁻¹)

D = Annual decomposition rate (1.6% year⁻¹), NOM= Amount of N contained in soil organic matter (kg N ha⁻¹) and CEC = Cation exchange capacity (cmol+ kg⁻¹ soil).

The gaseous N losses through denitrification and volatilization were estimated by using regression model developed by IFA and FAO [18]:

Gaseous N losses = (0.025+0.000855×P+0.01725×F+0.117×O)+0.113×F

Where

P = Annual precipitation (mm), F = Mineral and organic fertilizer nitrogen applied (kg N ha⁻¹) and O= Organic carbon content (%).

The surface partial nutrient balance for the system was calculated as:

N N_ab= N_inp (Nf,Nm,Wr,Nr, N_fix,Nc)- N_outp (N_up,Nl,Ng)

P N_ab= N_inp (Nf,Nm,Nr,Nc)- N_outp (N_up)

K N_ab=N_inp (Nf, Nm, Nr, Nc)-N_outp (N_up, Nl)

Where N_ab, P N_ab and K N_ab are the surface N, P and K balances, respectively; N_inp is the nutrient additions/inputs through mineral fertilizer (Nf), poultry manure (Nm), wheat straw (Wr), rainwater (Nl), atmospherically fixed nitrogen (N_fix) and recycled crop residues (Nc); N_outp is the nutrient removal/ output through uptake by grain and straw (for wheat) and grain and stalk (for soybean) (N_up), leaching (Nl) and gaseous losses (Ng). The N, P and K concentrations in rainwater were measured occasionally during 2009-2011 at the experimental site (Rawalakot). The measured data for all primary nutrients is variable in terms of inputs and outputs, therefore, the traditional analysis of variance (ANOVA) and least significant difference (LSD) test were not performed.

**Results and discussion**

**Surface nitrogen balance**

Averaged over a period of three years, the surface N balance showed a deficit of N (-41.2 kg ha⁻¹·year⁻¹) for the control soil. Application of different amendments and their combinations resulted in the positive N
balance that varied between +40.7 to +86.8 kg ha\(^{-1}\) year\(^{-1}\) (Table 4). Maximum positive N balance was recorded for the WSR\(_{100}\) amended soil while the minimum was observed in case of UN\(_{100}\) treatment followed by PM\(_{50}\)+WSR\(_{50}\). The maximum positive N balance in the WSR amended soil reflected the slower mineralization of the WSR and higher retention in the soil. The N leaching losses varied between 10.4 to 26.9 kg ha\(^{-1}\) year\(^{-1}\). The magnitude of N losses through leaching was maximum for the WSR\(_{100}\) followed by the treatment where both organic amendments were combined together i.e. PM\(_{50}\)+WSR\(_{50}\). The higher N losses from WSR treated soil may be associated with late release of N from the WSR when crop demand for N diminishes. The N losses recorded in our study were higher than those of 22.2 kg N ha\(^{-1}\) year\(^{-1}\) reported by [19] where they applied N at the rate of 200 kg ha\(^{-1}\) at the time of planting. The higher leaching losses in our case may be the result of higher total N applications (600 kg N ha\(^{-1}\)) over three years and poor synchronization between N release and crop N uptake.

Among the organic amendments (PM, WSR and PM+WSR), the N balance ended up with 70.2, 23.1 and 28.0 percent increase over the treatments where these amendments were combined with half UN. Similarly, among the combined treatments, the application of UN with WSR in UN\(_{50}\)+WSR\(_{50}\) recorded higher leaching losses compared to the remaining two combined N treatments. The asynchronization between the N release from organic amendments and the crop N demand at later growth stages could promote the leaching of the N released from organic amendments.

The results of the present study indicated that the control soil showed negative N balance of -41.2 kg ha\(^{-1}\) year\(^{-1}\) during three years of experimentation because no nitrogen input was added to the control soil. Our results are supported by the findings of [20] where they reported the negative nutrient balance (-70 kg N, -3 kg P and -21 kg K ha\(^{-1}\) year\(^{-1}\)) for the un-amended soil. Among different amendments, the application of organic amendments particularly WSR\(_{100}\) recorded the highest positive N balance of 86.8 kg ha\(^{-1}\) year\(^{-1}\), suggesting the slow and late release of N from WSR through mineralization and subsequently lower N uptake. The soil application of low quality crop residues limits nutrients availability to crops during early growth stages by extending the period of nutrients immobilization and results in poor synchronization and lower nutrient uptake [21]. Moreover, the soybean grown under organic treatments, exhibited higher N\(_2\) fixation due to improved soil physical conditions, added considerable amounts of crop residues and contributed to the positive soil N balance. The amount of N originally added to the soil system greatly depends on the amount of N translocated to the grains and on the amount of N recycled into the soil through crop residues [22]. The recycling of large amounts of crop residues into the soil from high N\(_2\) fixing soybeans and other legumes improves the N economy of cropping systems by adding additional N and positively affects soil N balance [23]. The soybean and other grain legumes meet 50-80 percent of their N requirements by fixing the atmospheric N and remove small amounts of soil mineral N than cereals thereby, positively contributing to N balance because of their ‘sparing effects’ and contribution through residue additions [24, 25]. The treatment receiving UN at the rate of 200 kg N ha\(^{-1}\)year\(^{-1}\) showed marginal build up of soil N (40.7 kg N ha\(^{-1}\) yr\(^{-1}\)) compared to all other treatments. The higher uptake of N from applied urea during early stages of growth and its leaching losses altogether might be the possible reason of lower positive N balance in UN amended soil.
Table 4. Nitrogen balance of surface soil under wheat-soybean cropping following the application of poultry manure (PM), wheat straw residues (WSR), urea nitrogen (UN) and their combinations at Rawalakot, Azad Jammu and Kashmir (Average of 3 years: 2009, 2010 and 2011)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fertilizer</th>
<th>Poultry manure</th>
<th>Wheat straw residues (as amendment)</th>
<th>Addition by soybean residues</th>
<th>Addition by wheat residues</th>
<th>N₂-fixed by soybean</th>
<th>Rainfall</th>
<th>Total</th>
<th>Crop removal by</th>
<th>Leaching losses</th>
<th>Gaseous losses</th>
<th>Total</th>
<th>Surface nitrogen balance (kg ha⁻¹year⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>21.2</td>
<td>10.0</td>
<td>57.6</td>
<td>0.55</td>
<td>89.4</td>
<td>34.6</td>
<td>94.7</td>
<td>Nil</td>
<td>1.3</td>
<td>130.5</td>
</tr>
<tr>
<td>PM₁₀₀</td>
<td>0</td>
<td>200</td>
<td>0</td>
<td>28.7</td>
<td>14.4</td>
<td>71.5</td>
<td>0.55</td>
<td>315.1</td>
<td>61.8</td>
<td>134.1</td>
<td>20.9</td>
<td>27.3</td>
<td>244.1</td>
</tr>
<tr>
<td>WSR₁₀₀</td>
<td>0</td>
<td>0</td>
<td>200</td>
<td>23.8</td>
<td>13.4</td>
<td>61.4</td>
<td>0.55</td>
<td>299.2</td>
<td>50.5</td>
<td>107.7</td>
<td>26.9</td>
<td>27.3</td>
<td>212.4</td>
</tr>
<tr>
<td>UN₁₀₀</td>
<td>200</td>
<td>0</td>
<td>0</td>
<td>30.7</td>
<td>17.7</td>
<td>57.7</td>
<td>0.55</td>
<td>306.7</td>
<td>74.3</td>
<td>153.8</td>
<td>10.5</td>
<td>27.3</td>
<td>266.0</td>
</tr>
<tr>
<td>PM₅₀+ WSR₅₀</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>25.0</td>
<td>13.1</td>
<td>63.0</td>
<td>0.55</td>
<td>301.7</td>
<td>55.2</td>
<td>113.7</td>
<td>24.9</td>
<td>27.3</td>
<td>221.1</td>
</tr>
<tr>
<td>UN₅₀+ PM₅₀</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>33.8</td>
<td>16.5</td>
<td>58.8</td>
<td>0.55</td>
<td>309.7</td>
<td>79.8</td>
<td>150.5</td>
<td>10.4</td>
<td>27.3</td>
<td>268.0</td>
</tr>
<tr>
<td>UN₅₀+ WSR₅₀</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>30.7</td>
<td>15.0</td>
<td>59.9</td>
<td>0.55</td>
<td>306.2</td>
<td>58.7</td>
<td>129.9</td>
<td>19.7</td>
<td>27.3</td>
<td>235.7</td>
</tr>
<tr>
<td>UN₅₀+ PM₂₅+ WSR₂₅</td>
<td>100</td>
<td>50</td>
<td>50</td>
<td>31.3</td>
<td>15.4</td>
<td>65.7</td>
<td>0.55</td>
<td>312.9</td>
<td>65.9</td>
<td>139.4</td>
<td>17.3</td>
<td>27.3</td>
<td>249.9</td>
</tr>
</tbody>
</table>

UN= urea nitrogen, PM= poultry manure and WSR= wheat straw residues
In UN sub 100 treatment, the N export in the wheat and soybean products (grain + straw) represented 85.8 percent of the total output with the corresponding leaching loss of 10.5 kg N ha\(^{-1}\) year\(^{-1}\) i.e. 2.2 to 5.3 percent of the total applied N. The leaching losses calculated in our study are generally lower than that reported by [26] where they observed 9.0 percent translocation of applied N into the deeper soil layers in a field experiment on maize crop. These results agreed with the findings of [27] who reported that plants can remove most of the N added through mineral fertilizers during the year of application, leaving little amount in soil for subsequent use or leaching. The higher leaching losses might be due to higher rainfall (> 1388 mm year\(^{-1}\)), lack of synchronization between N release and crop demand and subsequently lower total N uptake by the crops. N-based applications of organic amendments in excess of crop demand increase the chances of NO\(_3\) leaching. Over three years, the combined N treatments recorded lower soil N balance (41.7-70.5 kg N ha\(^{-1}\) yr\(^{-1}\)) compared to the soil treated with organic amendments (70.9-86.8 kg N ha\(^{-1}\) yr\(^{-1}\)). The average maximum annual soil N balance in our case for combined treatment (UN sub 50+WSR sub 50) was 70.5 kg N ha\(^{-1}\) yr\(^{-1}\) and strongly agreed with the findings of [28] who reported 87 kg ha\(^{-1}\) annual additions of N to the soil of Nigeria following the combined application of organic and mineral fertilizers. The balanced supply of N, P, K and other essential nutrients from organic-inorganic amendments, improved growth and higher total nutrient uptakes may be responsible for decreased N balance in soil under combined treatments. [29] observed 8-12 percent decrease in soil N balance only due to the application of 200 kg K ha\(^{-1}\) because of increased N concentration and uptake in tomatoes.

**Surface phosphorus balance**

The P balance observed under different treatments (Table 5) indicated that the control soil recorded the minimum P uptake of 16.4 kg ha\(^{-1}\) year\(^{-1}\) with a corresponding positive P balance of 83.7 kg ha\(^{-1}\) year\(^{-1}\) by the end of third year. Among different amendments, the PM sub 100 alone recorded the maximum P gain of 196.3 kg ha\(^{-1}\) year\(^{-1}\) over three years followed by PM sub 50+WSR sub 50 i.e. 166.3 kg ha\(^{-1}\) year\(^{-1}\), against the minimum P balance of 66.7 kg ha\(^{-1}\) year\(^{-1}\) in case of UN sub 100. The highest P balance observed in PM sub 100 treatment was probably due to the P contribution from PM, which additionally added 125 kg P ha\(^{-1}\) year\(^{-1}\) (more than that from P fertilizer i.e. 100 kg P\(_2\)O\(_5\) ha\(^{-1}\) year\(^{-1}\), a total of 376 kg P ha\(^{-1}\) in three years. In case of WSR sub 100 amended soil, the P balance was 57.3 percent higher compared to the control soil due to the contribution of P from WSR. When compared with combined N treatments, the organic amendments (PM, WSR and PM+WSR) increased the P balance by 47.2, 27.3 and 36.0 percent, respectively. For the combined N treatments, the application of UN sub 50+PM sub 50 recorded 9.0-22.7 percent higher P accumulations, compared to the remaining two treatments i.e. UN sub 50+WSR sub 50 and UN sub 50+PM sub 25+WSR sub 25. The results indicated that all treatments (including control) exhibited positive P balance for the three years. The magnitude of P build up was higher for the organic amendments compared to the combined N treatments and maximum P accumulation was observed for the soil amended with PM sub 100. The sum basal applications of 300 kg P\(_2\)O\(_5\) through SSP fertilizer plus extra addition of 376 kg P ha\(^{-1}\) from PM (altogether 676 kg P) and lower total P uptake (91 and 87 kg total P-uptake (i.e. 13 and 12 percent of the total P-input) was probably responsible for higher P accumulations in PM amended soil.
Table 5. Phosphorus balance of surface soil under wheat-soybean cropping following the application of poultry manure (PM), wheat straw residues (WSR), urea nitrogen (UN) and their combinations at Rawalakot, Azad Jammu and Kashmir (Average of 3 years: 2009, 2010 and 2011)

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Crop yields (kg ha(^{-1}) year(^{-1}))</th>
<th>P-input (kg ha(^{-1}) year(^{-1}))</th>
<th>P-output (kg ha(^{-1}) year(^{-1}))</th>
<th>Surface phosphorus balance (kg ha(^{-1}) year(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wheat soybean Fertilizer Poultry manure Wheat straw residues Rainfall Total</td>
<td>Crop removal Wheat soybean Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1203 1024 100 0 0 0.17 100.3 6.7 9.7 16.4 83.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM(_{100})</td>
<td>1855 1246 100 125 0 0.17 225.7 15.0 14.1 29.1 196.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WSR(_{100})</td>
<td>1593 1080 100 0 60 0.17 160.3 9.5 14.0 23.5 136.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UN(_{100})</td>
<td>2142 1463 100 0 0 0.17 100.3 14.8 18.5 33.4 66.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM(<em>{50})+ WSR(</em>{50})</td>
<td>1726 1121 100 63 30 0.17 193.0 11.3 15.0 26.4 166.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UN(<em>{50})+ PM(</em>{50})</td>
<td>2164 1327 100 63 0 0.17 163.0 17.4 19.1 36.4 126.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UN(<em>{50})+ WSR(</em>{50})</td>
<td>1821 1266 100 0 30 0.17 130.3 13.6 14.5 28.0 102.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UN(<em>{50})+ PM(</em>{25})+WSR(_{25})</td>
<td>1896 1300 100 31 15 0.17 146.7 14.6 15.8 30.4 116.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

UN= urea nitrogen, PM= poultry manure and WSR= wheat straw residues
The higher P levels in organically amended soil may also be associated with slower mineralization of added organic P. These results are supported by [30] who explained that major portion of P added to soil through organic amendments exists in organic fractions that get mineralized slowly over time. There was a three-fold increase in soil P level as compared to the values that were obtained before the start of experiment due to continuous application of poultry litter [10, 31].

Moreover, [30] reported that 73 percent higher P accumulations in soil following the repeated application of PM for three consecutive years in a rice-wheat cropping sequence compared to the NPK fertilizer alone. Similarly, [32] reported higher residual P accumulations under organic inputs than mineral counterparts. Moreover, the application of PM at rates to meet N requirements of crops results in excessive P accumulation in the amended soil. Some other researchers [31, 33] had reported the eutrophication of ground water due to the leaching and runoff losses of excessively accumulated soil P. The minimum P balance in UN100 treatment may be the result of higher total P uptake and small extra P additions (47 to 53 kg P ha\(^{-1}\) over three years) through the recycled wheat-soybean crop residues. Among the combined treatments, the P balance of the UN50+PM50 treatment was 22.8 and 9.0 percent higher compared with other two combined treatments i.e. UN50+WSR50 and UN50+PM25+WSR25, respectively. The comparatively low P additions in soil under combined treatments was probably due to higher total P uptake by both crops and small contribution of applied organic amendments. [28] Reported upto 33 kg annual P additions in soils due to combined application of organic manures and mineral N fertilizers. The reason for higher P values in our experiment is that we have summarized the P additions of all the three years of study instead of average annual values. The magnitude of soil P accumulation for all the treatments receiving the combination of PM followed the decreasing order: PM100> PM50+WSR50>UN50+PM50> UN50+PM25+WSR25.

**Surface potassium balance**

Averaged over a period of three years, the K balance in the control soil under the wheat-soybean cropping systems remained slightly positive (16.5 kg K ha\(^{-1}\)year\(^{-1}\)). A total basal application of 300 kg K\(_2\)O ha\(^{-1}\) from sulphate of potash (SOP) over three years is responsible to increase and maintain the positive K balances in the control soil. In most of the cases, the application of organic amendments and their combinations with half UN recorded positive K balances over three years that varied between +1.3 to 16.5 kg ha\(^{-1}\). However, the application of UN alone and with PM in UN100 and UN50+PM50 treatments showed negative K balances of -12.3 and -17.1 kg K ha\(^{-1}\)year\(^{-1}\), respectively (Table 6). The negative K balances in these two treatments could be associated with higher K-uptake by the crops (83.0 percent of the total K output), indicating the need for more K addition to sustain crop yield. Among all the amendments, the application of WSR100 at both the sites recorded the maximum positive K balances followed by PM50+WSR50.

Averaged over the three years, the K leaching losses among the amendments varied between 26.7 to 34.2 kg ha\(^{-1}\)year\(^{-1}\), representing the relative increase of 10.0 to 40.9 percent, respectively, over to the control. In spite of high total rain fall, the lower K losses through leaching might be associated with fine soil texture (higher clay contents) and slower release of K from the added amendments during winter.

Results of our study revealed that the control soil recorded the positive K balance of 16.5 kg ha\(^{-1}\)year\(^{-1}\) with the corresponding leaching loss of 24.3 kg K ha\(^{-1}\)year\(^{-1}\). The positive K balance in the control soil may be due to the
annual additions of 100 kg K\(_2\)O ha\(^{-1}\) from
sulphate of potash (SOP) over a period of
three years. The K losses recorded in our
study for the control treatment were
approximately five times higher than the K
loss of 15 kg ha\(^{-1}\) reported by [34] from
the control soil after three years of soybean-
wheat cropping. The K application from both
SOP and organic amendments beyond crop
requirement and higher monsoon rainfall are
the possible causes of higher losses in our
study. Among different amendments, the
application of UN alone or with PM (i.e.
UN\(_{100}\) and UN\(_{50}\)+PM\(_{50}\)) recorded the
negative K balance of -12.3 and -17.1 kg ha\(^{-1}\)year\(^{-1}\), respectively. This negative K balance
may be associated with the removal of K in
large amounts through plant uptake and
leaching and low K contents of applied PM.
The values of negative K balance recorded in
our study are comparable with those reported
by [35] where the values of negative K
balance varies from -6.9 (in NK amended
plots) to -82.2 kg ha\(^{-1}\) yr\(^{-1}\) (for N+ FYM
treated plots). Similarly, [36] also reported
negative soil K balance for the treatment
receiving combined application of PM +
mineral N fertilizer over four consecutive
years. In addition, [37] also reported negative
K balances of -52.2 to 181.5 kg ha\(^{-1}\) yr\(^{-1}\) in
their long-term (28 years) experiments for
integrated nutrient management in rice-wheat
cropping systems at Bihar, India.
The maximum increase in K balance (37-64
percent over control) was recorded for the
treatment receiving WSR\(_{100}\) at both the sites.
Despite of substantial leaching losses of K
from WSR amended soil (21.6 to 22.1
percent of the total K output), the higher K
build up was attributable to the highest total
K input of 556.3 to 573.9 kg ha\(^{-1}\) from the
recycled residues+ K fertilizer and lowest K-
uptake by the crops among all treatments.
The increased leaching losses of K from
WSR amended soil reflect higher K release
from the added WSR. [38] explained that the
K in mature plant residues exists in ionic
form and soil incorporation of such type of
residues quickly release K into the soil
solution from where it is either taken up by
the growing plants or lost through leaching.
The contribution of 12 kg ha\(^{-1}\) extra K
addition through WSR during three years,
slower mineralization rates, lack of
synchrony between K release and uptake by
crop and consequently lower total K uptake
by the crop are mainly responsible for the
increased accumulation of K in WSR
amended soil.
Among the combined N treatments, the K
balance for the UN\(_{50}\)+WSR\(_{50}\) and
UN\(_{50}\)+PM\(_{25}\)+WSR\(_{25}\) was substantially lower
compared to the control and varied between
1.3-5.2 kg ha\(^{-1}\) year\(^{-1}\). The higher K uptake by
plants and increased leaching losses of
applied K from these two combined
treatments may be the possible cause of this
difference. When expressed on annual basis,
the K leaching losses recorded in our
experiment under different amendments
(26.7-34.2 kg ha\(^{-1}\)year\(^{-1}\)) are much closer to
the values (32.0 kg K ha\(^{-1}\)year\(^{-1}\)) reported by
[39] for a NPK+FYM amended soil under a
long-term (30 years) experiment.
Table 6. Potassium balance of surface soil under wheat- soybean cropping following the application of poultry manure (PM), wheat straw residues (WSR), urea nitrogen (UN) and their combinations at Rawalakot, Azad Jammu and Kashmir (Average of 3 years: 2009, 2010 and 2011)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Crop yields (kg ha(^{-1}) year(^{-1}))</th>
<th>K-input (kg ha(^{-1}) year(^{-1}))</th>
<th>K-output (kg ha(^{-1}) year(^{-1}))</th>
<th>Surface potassium balance (kg ha(^{-1}) year(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wheat Soybean</td>
<td>Fertilizer Poultry manure Wheat straw residues Addition by soybean residues Addition by wheat residues Rainfall Total Crop removal by Wheat Soybean Leaching losses Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1203 1024</td>
<td>100 0 0 12.0 15.7 0.4 128.1 39.1 48.2 24.3 111.6</td>
<td>16.5</td>
<td></td>
</tr>
<tr>
<td>PM(_{100})</td>
<td>1855 1246</td>
<td>100 23 0 15.2 20.5 0.4 159.5 55.8 61.1 31.8 148.7</td>
<td>10.8</td>
<td></td>
</tr>
<tr>
<td>WSR(_{100})</td>
<td>1593 1080</td>
<td>100 42 15.3 27.5 0.4 185.4 62.9 61.0 34.2 158.1</td>
<td>27.3</td>
<td></td>
</tr>
<tr>
<td>UN(_{100})</td>
<td>2142 1463</td>
<td>100 0 18.1 23.6 0.4 142.0 54.3 73.4 26.7 154.4</td>
<td>-12.3</td>
<td></td>
</tr>
<tr>
<td>PM(<em>{50})+ WSR(</em>{50})</td>
<td>1726 1121</td>
<td>100 21 14.7 20.9 0.4 168.8 59.1 61.9 31.3 152.3</td>
<td>16.5</td>
<td></td>
</tr>
<tr>
<td>UN(<em>{50})+ PM(</em>{50})</td>
<td>2164 1327</td>
<td>100 0 17.1 22.8 0.4 152.0 69.6 71.1 28.4 169.1</td>
<td>-17.1</td>
<td></td>
</tr>
<tr>
<td>UN(<em>{50})+ WSR(</em>{50})</td>
<td>1821 1266</td>
<td>100 21 17.2 26.2 0.4 164.9 65.1 63.9 30.7 159.7</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>UN(<em>{50})+ PM(</em>{25})+ WSR(_{25})</td>
<td>1896 1300</td>
<td>100 6 11 16.6 22.7 0.4 156.1 60.4 65.2 29.1 154.8</td>
<td>1.3</td>
<td></td>
</tr>
</tbody>
</table>

UN= urea nitrogen, PM= poultry manure and WSR= wheat straw residues
Conclusion
These 3-year field experiments on wheat-soybean cropping under integrated nutrient management have provided a framework that organic amendments particularly wheat straw residues, alone and along with urea N, have the potential to improve NPK balance of surface soil. Whereas, the soil amended with UN, PM or UN+PM combinations displayed marginal increases in N and P balance. Although, the organic amendments alone showed little improvements in crop yield during three years but their positive contribution towards improving overall soil quality and nutrient status of degraded soils cannot be ignored. Therefore, these results suggested the application of organic amendments (of plant and animal origin) with mineral N fertilizer for improving both wheat–soybean productivity and nutrient levels of degraded soils under the hilly agro-ecosystem of Himalayan region of Azad Jammu and Kashmir. The study further revealed that the K fertilization practiced in our experiments at the rate of 50 kg K₂O ha⁻¹ year⁻¹ is insufficient and need to be increased to rectify the K imbalance and sustain crop yields in the region. These findings highlight that the combined application of WSR and mineral fertilizers can help to build up N and P stocks in surface soil.

Authors’ contributions
Conceived and designed the experiments: Khaliq A & Abbasi MK, Performed the experiments: Khaliq A, Analyzed the data: Zafar M & Sarwar S, Contributed materials/analysis/tools: Khaliq A, Zafar M & Tahir MM, Wrote the paper: Khaliq A & Zafar M.

References
Buresh RJ, Sanchez PA & Calhoun F (eds.) Replenishing soil fertility in Africa.


