Effect of application methods of organic fertilizer on growth, soil chemical properties and microbial densities in organic bulb onion production

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ABSTRACT

This study was carried out to maximize the fertilization efficiency of mixed organic fertilizer (OF) for organically managed onion (Allium cepa L.) production during the one growing season of 2005–2006. The organic fertilizer was made of organic materials like sesame oil cake, rice bran and molasses and minerals like ilite and mountainous soil. Four organic topdressing treatments, which all followed the same basal fertilization with solid OF, consisted of solid OF without mulch (OF/OFnM), liquid organic fertilizer without mulch (OF/LOFnM), liquid organic fertilizer under mulch (OF/LOFuM) and liquid organic fertilizer over mulch (OF/LOFoM). Chemical fertilizer (CF) and no fertilizer (NF) were treated as controls. The solid organic fertilization base was 2.0 ton ha⁻¹, and 4.57 ton ha⁻¹ and was used for topdressing. The total amount of liquid organic fertilization was 133.2 ton ha⁻¹, which was divided into 6 applications from February through March. The OF/LOFuM and OF/LOFoM topdressings did not reduce onion height, leaf number or bulb diameter as compared to chemical fertilizer, whereas no mulch treatments made onion growth significantly poorer. Onion top weight in CF was significantly higher than that in OF groups at the peak growth stage, while there was no much difference in bulb weight between the CF and OF/LOFoM treatment. Finally, the onion marketable yield was 45.9 ton ha⁻¹ in the OF/LOFoM treatment, which exceeded that in the CF treatment by up to 1.9 ton. Furthermore, OF/LOFoM was the most effective among all the treatments in transferring the nutrients from sink to source. CF made the soil pH more acidic than OF did, and the electrical conductivity (EC) remained higher with CF than OF as well. While organic fertilizer helped to keep the NO₃-N content stable throughout the growing season, the concentration rapidly oscillated up and down according to CF fertilization. Organic fertilizer increased population number of soil microorganisms like aerobes, actinomycetes in the field.

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1. Introduction

The transition from conventional to organic farming is accompanied by changes in an array of soil chemical and biological properties and processes that affect soil fertility. Fundamental differences, both qualitative and quantitative, in the flow and processing of nutrients result from soil amendment, plant community structure, tillage, and elimination of synthetic fertilizers and pesticides (Bossio et al., 1998; Clark et al., 1998). Studies comparing soils of organically and conventionally managed farming systems have documented higher soil organic matter and total N with the use of organic practices (Alvarez et al., 1988; Drinkwater et al., 1995; Reganold, 1988). Increases in soil organic matter following the transition to organic management occur slowly, generally taking several years to detect, but can have a dramatic effect on long-term productivity (Clark et al., 1998; Drinkwater et al., 1995; Wander et al., 1994). Changes in other soil properties have been found to be more variable, perhaps due to differences in climate, crop rotation, soil type, or length of time a soil has been under organic management (Drinkwater et al., 1995; Werner, 1997). Soil pH becomes higher, plant-available nutrient concentrations may be higher and the total microbial population increases under organic management (Clark et al., 1998; Dinesh et al., 2000; Reganold, 1988).

Organic fertilizers, which mainly come from crop residues like rice bran, various oilseed cakes and animal byproducts like meat bone meal, blood meal, fish meal and crab meal, are sometimes distinguished from animal manure or compost based on animal waste. They contain specifically high levels of nutrients, e.g. N in oilseed cakes and blood meal and P in rice bran and meat bone meal, and are also high in organic matter content and a variety of micronutrients in general (Blatt, 1991; Cayuela et al., 2008), so that they have been widely used as alternative fertilizers for organically grown fields. However, the apparent deficiency of an adequate supply of plant-available N from organic fertilizer, resulting from a slow rate of mineralization, makes crop yields in fields treated with...
organic fertilizer lower than in those treated with chemical fertilizer (Blatt, 1991). Therefore, the application of organic N topdressing in the form of liquid organic fertilizer, often called compost extract or tea, during the growing season has been evaluated (Gross et al., 2008; Hadad and Anderson, 2004). Various organic materials have been recognized as soil amendments and disease controllers, including the control of brown spot disease and augmentation of bacterial numbers by rice bran (Osunlaja, 1989) and the increase in plant growth and reduction of nematodes population by oil cakes (Khan and Saxena, 1997). However, there have been problems like the accumulation of NO3 in vegetables and increased soil EC concentration in organic farming caused by excessive application of animal manure and organic fertilizer (Lee et al., 2004; Sohn et al., 1996).

One of the goals of nutrient management is to supply nutrients in a timely manner to maximize crop yield and quality. Cumulative nutrient uptake by an onion crop follows a sigmoid or s-shaped curve during the growing season and the period of rapid nutrient uptake starts during bulbing. Onions take up roughly at least 110 kg ha\(^{-1}\) of nitrogen, potassium and calcium, and substantially lower amounts of sulfur, phosphorus and magnesium (Sullivan et al., 2001). Nevertheless, onion root systems consist of superficial roots that are rarely branched and lack root hairs, requiring much larger supplies of nutrients than will be taken up through the field. An onion bulb responds little to nitrogen fertilization rates (Halvorson et al., 2008; Shock et al., 2004). Plastic mulches have been generally used for soil warming, moisture conservation and weed control in onion production as in production of many other vegetables (Islam et al., 2002). Polyethylene film, however, can reduce the efficiency of fertilizer use in the middle of the growing season, since the mulches hinder the infiltration of additional fertilizer into the soil around the onion root system (Yang et al., 2006). In addition, polyethylene film has not been regarded as an ecological input within organic farming practices (Moreno and Moreno, 2008).

The aim of this study was to examine how to apply organic fertilizer effectively during organic production of onions while, at the same time, enhancing the nutrient efficiency, soil fertility and microbes.

2. Materials and methods

2.1. Field experiment

The field experiment was conducted at the experimental farm of the Onion Research Institute, Changnyeong district, Korea (35°55′N latitude and 128°47′E longitude) from 2005 to 2006. The experimental site had been under continuous cultivation by a double cropping system of rice followed by bulb onion (Allium cepa L.) and managed organically without the use of any chemicals for 3 years before starting this experiment. The topsoil was a silty loam with the yield of onion bulb responds little to nitrogen fertilization rates (Halvorson et al., 2008; Shock et al., 2004). Plastic mulches have been generally used for soil warming, moisture conservation and weed control in onion production as in production of many other vegetables (Islam et al., 2002). Polyethylene film, however, can reduce the efficiency of fertilizer use in the middle of the growing season, since the mulches hinder the infiltration of additional fertilizer into the soil around the onion root system (Yang et al., 2006). In addition, polyethylene film has not been regarded as an ecological input within organic farming practices (Moreno and Moreno, 2008).

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<table>
<thead>
<tr>
<th>Treatments</th>
<th>Basal fertilization</th>
<th>Topdressing (N–P–K, kg ha(^{-1}))</th>
<th>Total rate (N–P–K, kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>NF</td>
<td>CF</td>
<td>(80–34–48)</td>
<td>(160–0–80)</td>
</tr>
<tr>
<td></td>
<td>OF/OFnM</td>
<td>2,000 (80–20–27)</td>
<td>4,570 (160–27–103)</td>
</tr>
<tr>
<td></td>
<td>OF/LOFnM</td>
<td>2,000 (80–20–27)</td>
<td>132,000 (160–4–43)</td>
</tr>
<tr>
<td></td>
<td>OF/LOFuM</td>
<td>2,000 (80–20–27)</td>
<td>132,000 (160–4–43)</td>
</tr>
<tr>
<td></td>
<td>OF/LOFoM</td>
<td>2,000 (80–20–27)</td>
<td>132,000 (160–4–43)</td>
</tr>
</tbody>
</table>

NF, no fertilizer; CF, chemical fertilizer; OF/OFnM, basal application of organic fertilizer (OF) and topdressing of solid OF without mulch; OF/LOFnM, basal application of OF and topdressing of liquid OF without mulch; OF/LOFuM, basal application of OF and topdressing of liquid OF under mulch; OF/LOFoM, basal application of OF and topdressing of liquid OF over mulch.

1154 mg N kg\(^{-1}\), 32 mg P kg\(^{-1}\), 324 mg K kg\(^{-1}\). The four organic treatments, which all had the same basal fertilization by solid OF, were different in the topdressing as follows: (1) solid OF without mulch (OF/OFnM), (2) liquid organic fertilizer without mulch (OF/LOFnM), (3) liquid organic fertilizer under mulch (OF/LOFoM) and (4) liquid organic fertilizer over mulch (OF/LOFuM). Chemical fertilizer (CF) and no fertilizer (NF) were treated as controls. The solid organic fertilizer rate was 2.0 ton ha\(^{-1}\) for the basal application (Table 1). It was incorporated by hand raking into the soil of the plots which had already been set up. The treatments were replicated three times in a randomized complete block design using 1.2 m × 14 m individual plots. For topdressing, the solid organic fertilizer was applied at the rate of 4.6 ton ha\(^{-1}\) on the surface soil with mulch, twice separately in the middle of February and March. The liquid fertilizer was supplied at the rate of 135.2 ton ha\(^{-1}\), which was divided into 6 applications with each occurring every 10 days from February through March. The OF/LOFoM treatment was fertigated in one line under the mulch and the OF/LOFuM treatment was sprayed over the mulch using a power supply. Onion crops in all plots had 20.0 ton of cow manure compost applied and were cultivated under conditions of no herbicides or pesticides. Weeds in onion field were controlled by hand weeding 3 times from early March to late April. In mulch, weeds were removed through the planting holes of onion stand by hand weeding hoe in early spring. And then transparent plastic film was covered with the soil collected from furrow to hinder sunlight penetrate through the film into soil. In no mulch, weeds grew slower and rarer than in mulch, so it was effective enough to remove weeds by hand weeding hoe 3 times. As the previous crop, rice was transplanted mechanically and not applied with any fertilizers and pesticides. Weeds were controlled by rice-duck farming method. The yield was produced approximately 4.0 ton ha\(^{-1}\). We cultivated rice crop without applying any fertilizer to sequester the residual nutrients in soil after onion harvest. The straw was cut, spread and incorporated into soil at rice harvest.

2.2. Plant and soil sampling

Crop plants were sampled at the 98th, 112th, 126th, 147th, 161st, 177th, 189th and 212th day after transplanting with 10 plants per replicate. The soil samples for soil chemical and microbiological analysis were collected from the surface layer (0–15 cm) at plant sampling points, with additional sampling at the 17th day before transplanting and at one day after basal fertilizer and compost application.

2.3. Plant growth and nutrient uptake analysis

After measuring plant height and bulb diameter, the onion plants were separated into the bulb and green leaves so that the
concentrated H$_2$O$_2$. Total N was measured by the Kjeldahl method. Available P$_2$O$_5$ and exchangeable K. OM was determined by the Tyurin method (Schollenberger, 1927), and NO$_3$-N was identified by the liquid OF over mulch. Days after transplanting. Within a column, means followed by the same letter are not significantly different ($p=0.05$) using Duncan’s multiple range test. Days after transplanting.

Fresh leaf weight and bulb weight could be measured. Samples at harvest were dried to constant weight at 70 °C. The dried samples were ground, weighed and dissolved in concentrated H$_2$SO$_4$ and concentrated H$_2$O$_2$. Total N was measured by the Kjeldahl method. P$_2$O$_5$ was measured colorimetrically with an ammonium–vandate–molybdate method (Gericke and Kurmies, 1952) and K, Ca and Mg were determined by an atomic absorption spectrophotometer (Smith-Hiefje 4000).

### 2.4. Soil chemical and microbiological analysis

Air-dried soil samples were analyzed for pH, EC, OM, NO$_3$-N, available P$_2$O$_5$ and exchangeable K, OM was determined by the Tyurin method (Schollenberger, 1927), and NO$_3$-N was identified by the reflectometry (RQ plus, Merck). The Lancaster method (RDA, 1988): 5 g soil was extracted with 20 ml of 0.33 M CH$_3$CHOOH, 0.15 M lactic acid, 0.03 M NH$_4$F, 0.05 M (NH$_4$)$_2$SO$_4$ and 0.2 M NaOH at pH 4.25) was used to determine the available P$_2$O$_5$. The atomic absorption spectrophotometer was used to measure extractable cations. Soil pH and EC were measured by pH meter and conductivity meter. The plate dilution method was used for the determination of numerous microorganisms using agar medium. The numbers of aerobic bacterial colony forming units (cfu) were enumerated on nutrient agar (Difco 213000). Pseudomonas isolation agar (Difco 0927-17-1) and actinomycetes isolation agar (Difco 0927-17-1) were used for Pseudomonas spp. and actinomycetes, respectively. The selective media for detection of fungi and Fusarium spp. were rose bengal agar (Difco 213832) and Fuarium selective medium (Komata, 1976), respectively. In order to count the number of microorganisms, 10.0 g of fresh soil was shaken with 90 ml of sterilized distilled water. From this suspension the serial dilution (1:10) was prepared and plate counts were performed in triplicate and the plates were incubated until growth occurred (usually 3–7 days).

### 3. Results and discussion

#### 3.1. Plant growth

No mulch inhibited onion plant growth during the whole growing season, which did not surpass the growth of the onion crop cultivated without fertilizer (Tables 2 and 3). Application of liquid organic fertilizer over or under the mulch (OF/LOFuM, OF/LOFoM) produced an almost equal growth as that of chemical fertilization in terms of plant height, number of leaves, bulb diameter and bulb weight. The top weight in the organic fertilization with mulch was lower than with chemical fertilization at the peak growth stage, 161 days after transplanting, but the same trend was not observed for bulb weight. The organic fertilization without mulch (OF/OFnM, OF/LOFnM) caused the onion crops to start regrowing about a month later than ones cultivated with mulch after winter. It is most likely due to lower soil temperature as Adams (1970) reported.

#### 3.2. Inorganic nutrient contents and uptakes of onion crop

Non-mulching cultivation with additional application of liquid organic fertilizer led to significantly higher inorganic nutrient content in the top (Table 4). This was attributed to insufficient nutrient transportation from top to bulb caused by delayed growth. The chemical fertilization resulted in a greater accumulation of total N and P$_2$O$_5$ concentrations as compared with organic fertilization. There was no organic fertilization method which exceeded chemical fertilization in the case of nutrient uptakes (Table 5). But the relative uptakes in the bulb out of the total crop in the OF/LOFoM treatment were T-N of 67.8% and K$_2$O of 81.4%. This suggests that the treatment improved N and K transportation from top to bulb, compared with CF, which had uptakes of T-N of 64.2%...
Table 5
Nutrient uptakes in tops and bulbs of onions at harvest as affected by different methods of applying organic fertilizer.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Top, kg ha⁻¹</th>
<th>Bulb, kg ha⁻¹</th>
<th>Total, kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T-N</td>
<td>P₂O₅</td>
<td>K₂O</td>
</tr>
<tr>
<td>NF</td>
<td>7.6b</td>
<td>0.6m</td>
<td>6.5b</td>
</tr>
<tr>
<td>CF</td>
<td>27.3a</td>
<td>1.4</td>
<td>42.9a</td>
</tr>
<tr>
<td>OF/OFnM</td>
<td>18.5a</td>
<td>1.2</td>
<td>41.3a</td>
</tr>
<tr>
<td>OF/LOFnM</td>
<td>19.1a</td>
<td>1.6</td>
<td>47.4a</td>
</tr>
<tr>
<td>OF/LOFuM</td>
<td>17.0a</td>
<td>1.1</td>
<td>23.0ab</td>
</tr>
<tr>
<td>OF/LOFoM</td>
<td>20.9a</td>
<td>1.9</td>
<td>21.6ab</td>
</tr>
</tbody>
</table>

Within a column, means followed by the same letter are not significantly different (p = 0.05) using Duncan’s multiple range test. NF, no fertilizer; CF, chemical fertilizer; OF/OFnM, basal application of organic fertilizer (OF) and topdressing of solid OF without mulch; OF/LOFnM, basal application of OF and topdressing of liquid OF without mulch; OF/LOFuM, basal application of OF and topdressing of liquid OF under mulch; OF/LOFoM, basal application of OF and topdressing of liquid OF over mulch.

Table 6
Total soluble solids and yield of onion bulbs as affected by different methods of applying organic fertilizer.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Total soluble solids (%)</th>
<th>Miss-planted rate (%)</th>
<th>Yield, ton ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Unsaleable</td>
<td>Total</td>
</tr>
<tr>
<td>NF</td>
<td>8.7a</td>
<td>6.2bc</td>
<td>0.7</td>
</tr>
<tr>
<td>CF</td>
<td>6.6c</td>
<td>8.6b</td>
<td>1.9</td>
</tr>
<tr>
<td>OF/OFnM</td>
<td>7.9b</td>
<td>13.5a</td>
<td>0.4</td>
</tr>
<tr>
<td>OF/LOFnM</td>
<td>7.5b</td>
<td>14.8a</td>
<td>0.2</td>
</tr>
<tr>
<td>OF/LOFuM</td>
<td>7.4b</td>
<td>5.6bc</td>
<td>0.7</td>
</tr>
<tr>
<td>OF/LOFoM</td>
<td>7.6b</td>
<td>3.2c</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Within a column, means followed by the same letter are not significantly different (p = 0.05) using Duncan’s multiple range test. NF, no fertilizer; CF, chemical fertilizer; OF/OFnM, basal application of organic fertilizer (OF) and topdressing of solid OF without mulch; OF/LOFnM, basal application of OF and topdressing of liquid OF without mulch; OF/LOFuM, basal application of OF and topdressing of liquid OF under mulch; OF/LOFoM, basal application of OF and topdressing of liquid OF over mulch.

Fig. 1. Changes in soil chemical properties produced by different methods of applying organic fertilizer. Vertical bars are the standard deviation (n = 3).
and K2O of 70.8% (ratio of N, K2O uptake in the bulb out of the total, data not shown).

3.3. Onion bulb yield

Application of liquid organic fertilizer over the mulch was effective in increasing the onion bulb yield. Total and marketable fresh weight yields are shown in Table 6. No significant yield difference was found between chemical fertilization and organic fertilization with mulch. There was a slight yield reduction in OF/LOFuM treatment compared with OF/LOFoM, possibly due to uneven distribution of applied nutrients which resulted from one-line fertigation. The total soluble solids of the onion bulbs in the organic fertilization groups ranged from 7.4% to 7.9%, which was significantly higher than that of CF treatment (Table 6). Compared to the group with incorporation of polyethylene mulch, the absence of mulch during the growing season significantly reduced yields by half the level of the other mulched treatments. This was attributed to delayed growth and a higher miss-planted rate over the course of winter. Some researchers have already reported that plastic mulch has a variety of benefits, including faster growth early in the season, soil moisture regulation, weed control, improved plant growth, etc. (Hanada, 2001; McCraw and Motes, 2007). However, organic mulches such as some cereal crop straws and cover crops show fairly positive promise as an alternative to plastic films in organically grown fields (Kesik, 2000; Shock et al., 1997).

3.4. Soil chemical properties

Significant differences between chemically and organically fertilized soils were found in pH, EC and NO3-N values (Fig. 1). Shortly after fertilization, rapid fluctuations in these values occurred in the chemical fertilization group. Specifically, the pH went down and NO3-N and exchangeable K2O contents increased as a direct response to chemical fertilizer application. The changes in EC showed a similar tendency to those of the NO3-N content, and their responses to fertilization were considerably more dramatic than the changes in pH. The soil pH before basal fertilization was 6.7 and after harvest it was nearly 6.5 in all treatment groups except for the CF treatment group, with a pH of 6.0. Organic matter content remained higher in the organic fertilization plots, especially in those topdressed with solid organic fertilizer, compared to the CF plot. Exchangeable K accumulated at harvest, especially in the chemical fertilization plot, from 0.50 to 1.03 cmol/kg. Among the organic fertilization groups, the soil EC and NO3-N content rose higher under conditions of non-mulching cultivation than mulching cultivation. This indicated that the fertilization nutrients were more available in the bare soil than in the mulched soil. Nevertheless, it was assumed that the lower soil temperature in the non-mulched soil caused the remarkably lower onion growth and yield (McCraw and Motes, 2007).

Clark et al. (1998) also found, like these findings that soluble P and pH were significantly higher in the organic and low-put

![Fig. 2. Changes in total viable culturable cells of soil microorganisms, as affected by the method of applying organic fertilizer. Vertical bars are the standard deviation (n=3).](image-url)
systems than in the conventional systems, whereas EC, soluble Ca and soluble Mg concentrations were higher in conventional systems. Electrical conductivity is a measure of the total numbers of cations and anions in solution and its levels have been found to be closely linked to NO3− concentrations in the soil (Partiriquin et al., 1993). Nitrification acidsifies the soil, bringing the cations into solution. Thus, soluble cations and EC levels are highly dependent on N fertility practices and would be expected to vary throughout the growing season as in the results of this study.

3.5. Soil microbial populations

The results of the microbial counts for each growth stage are shown in Fig. 2. Most soil microorganisms increased right after the compost and basal fertilizer were applied. The aerobic bacteria, actinomycetes and fungi were inclined to decrease in vial cell compost and basal fertilizer were applied. The aerobic bacteria, Fusarium spp. and Fusarium spp. hardly responded to the initial fertilization, but increased in numbers with rising temperature except for a rapid decline of Fusarium spp. after the 177th day (May 18). The population changes in Fusarium spp., a major soil-born pathogen causing wilt in onion crops, were in the agreement with the results obtained by Lee (1977) in that the highest populations of Fusarium spp. were observed on May 16 and July 29 in ginseng growing field.

The microbial counts did not statistically reveal differences from the CF or OF group. Nonetheless, the OF plots without mulch had relatively higher counts at some stages in aerobic bacteria, actinomycetes and fungi. The OF plots covered with mulch showed higher counts in spore-forming bacteria and Pseudomonas spp. The generally decreased microbial densities in the CF treatment are assumed to be due to lower soil pH and OM as compared with the OF treatment groups. It is known that organic matter introduced to the soil stimulates soil microbial populations and soil microbial activity (Brady and Weil, 1999; Chen and Avnimelech, 1986). Application of organic fertilizer as well as various composts generally caused an increase in bacteria, fungi and actinomycetes population compared to mineral fertilizer, but the patterns varied depending on the type of organic fertilizer (Krishnakumar et al., 2005), application rate (Lee et al., 2004; Mondini et al., 2008), soil type to which it was applied (Perez-Piqueres et al., 2006) and the time investigated (Kokalis-Burelle and Rodriguez-Kabana, 1994). In some cases, compost or farmyard manure did not significantly enhance any microbial density more than mineral fertilizer (Lafalkzuala et al., 2008).

This result also showed that the effect of the organic fertilizer on microorganism populations was not always the same or consistent throughout the whole season. Nevertheless, actinomycetes from organic fertilizer group increased rapidly right after fertilization. Aerobic bacteria and actinomycetes were relatively abundant in organic plot during the middle of season. No mulch and organic fertilizer suppressed pathogenic Fusarium spp. in the late season. The organic fertilizer therefore, had a positive effect to soil microbial community through some period of growing season.

4. Conclusion

The organic fertilizer application results in reduced growth in terms of plant height, and number of leaves. Organically managed onions were also lower in top weight, and nutrient uptakes in onion plant compared with chemical fertilizer application. The organic fertilizer however, enhanced the total soluble solids in the onion bulb harvested. In addition, it did not show any significant differences of bulb yield as compared with chemical counterpart under the same condition of mulch. The results of my study indicate that the use of organic fertilizer, especially topdressing by liquid fertilizer applied over mulch, results in stable soil pH and NO3−N levels over the growing season. Furthermore it increased organic matter content and microorganism populations in soil, which can provide long-term fertility benefits and onion productivity improvement. Although no mulch caused less onion yield, the adaptation of cover crops or organic mulch might be expected to increase onion bulb yield while maintaining the ecological benefits of non-plastic mulching cultivation. The stable soil pH and increased organic matter content and exchangeable K were due to application of organic fertilizer, which might have positive effect on the succeeding rice crop cultivation. Further research on application of organic fertilizer in onion cultivation needs to be conducted to test its residual effect on the rice crop, in particular in terms of soil fertility and environmentally sound practices.

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