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RESEARCH ARTICLE

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# Characterization of cowpea to harvest rainwater for wheat in semiarid conditions

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## Abstract

*Aim of study:* A field experiment was executed, under rainfed conditions from 2014-15 to 2017-18, to study the role of cowpea (*Vigna unguiculata* L.) in rainwater harvesting to enhance the wheat (*Triticum aestivum* L.) yield.

*Area of study:* Rain-fed area of Pothwar region, Punjab, Pakistan.

*Material and methods:* We designed three treatments (T1: control; T2: cowpea grown after conventional tillage and incorporated into soil to act as "green manure"; and T3: grown without any tillage practice, cut with sickle and spread as "mulch"). The effect of these treatments on soil moisture conservation was studied against conventional farmer's practice, wherein no host crop is grown before wheat sowing.

*Main results:* Available soil water remained highest in T2 during first three years when sufficient rainfall was received contrary to fourth year with low rainfall. The results revealed that cowpea biomass of 15.2 t/ha and 13.72 t/ha, from T2 and T3 respectively, were produced during 2015 corresponding to 213 mm rainfall. Whereas, these quantities increased to 25.69 t/ha and 24.29 t/ha during 2017 with 387 mm of rainfall. The study revealed that net income from wheat crop under T2 was Rs 13000 and Rs 9000 per hectare higher than that of control during the first two years respectively. Contrarily, net income from T2 was found negative and benefit-cost ratio reduced to 0.79 when very low rainfall was received during the last year.

*Research highlights:* Use of cowpea as green manure gave maximum net return if sufficient rainfall is received during decomposition of cowpea and hence recommended for in-situ rainwater harvesting.

**Additional key words:** *Vigna unguiculata* L.; conservation tillage, in-situ moisture conservation; green manure; mulching; rainwater harvesting.

**Abbreviations used:** BCR (benefit cost ratio), GM (green manure),

**Authors' contributions:** Conceived idea, planned, executed and collected data: MRS, WN, SAR. Analyzed the soil samples in laboratory: WN, MRS. Drafted the manuscript: RR, SAR. Compiled the data tables, prepared graphs and critically reviewed, revised & refined the manuscript: SAR, AK, GM, AS. Statistical analysis: RR, WN. Literature revision, edition of the manuscript: AK, MA, SJ. All authors read and approved the final article.

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# Introduction

Water is crucial for life and rain is the major source of water in Pothwar region of Pakistan. The agriculture in rainfed areas having sloppy lands like Pothwar is often confronted with two main problems *i.e.*, soil erosion and water stress (SAWCRI, 2020). The careful husbandry of soil and water is essential for food security and environmental protection. Mismanagement of rainwater has caused above mentioned twin menace in the area. Annual average rainfall in the area ranges from 300-1000 mm, which is near sufficient to fulfill crop water requirements (Rashid *et al.*, 2012; Salma *et al.*, 2012). However, the rainfall in the area is erratic in terms of availability on demand due to insufficient facilities of water storage in the area (Blanco & Lal, 2008). It is, therefore, vital to use rainwater in-situ (*i.e.*, where it falls) and/or store the rainwater for its subsequent use as per demand. In-situ storage and conservation of rainfall is being practiced in various parts of rainfed areas globally. Alongside the other methods, incorporation of green crops in the soil and various types of mulches can conserve water as soil moisture to fulfill major part of crop water requirement and current study is a test of this view. The other issue of the area is soil erosion that is mainly caused by overland flow of rainwater. During high intensity rainfall showers the top layer of fertile soil erodes and fertility is lost. This issue can also be addressed by using the above techniques. Global climate change has resulted in erratic rainfall, longer dry spells and decreased water availability to crops around the world (IPCC, 2007; Marris, 2008; Milly *et al.*, 2008). Rainfed agriculture is more sensitive to climatic variations (Hanjra & Qureshi, 2010). Major agricultural area around the world is rainfed with 60% share in crop production; they cover 80% of global agricultural area (WWAP, 2009). Nevertheless, agricultural production is quite less in arid and semi-arid parts of rainfed agriculture due to erratic rainfall, poor soil and water management practices (Rockstrom *et al.*, 2010).

Water and soil must be conserved by adopting sustainable practices. It has become essential to find sustainable ways to increase the yield, productivity and profitability by minimizing the cost of production. Intensive cropping pattern, excessive growth of weeds and unsafe agricultural practices, *e.g.* excessive tillage result in erosion, with no soil replenishment plan results in soil moisture depletion and degradation of productive land. Soil nutrient deficiency is overcome by applying different kinds of organic and inorganic fertilizers *e.g.* compost, mulch, green manuring, farmyard manure and artificial fertilizers (urea, di-ammonium phosphate, single super phosphate). However, organic fertilizers are safer and eco-friendly. There is a rising scope of organic amendments in providing healthy food for population. Addition of organic matter is known to influence some of the important soils physical, chemical and biological properties (Trisdal, 1989). The improvement of soil physical characters are the main benefits of organic amendments; however, the organic content is quite low in most of agricultural soils around the world. It also enhances soil biological activities by increasing mineralization rates and nutrient cycling (Dick, 1992; Pinamonti, 1998). Addition of organic matter decrease fertilizer requirements (Evanylo *et al.*, 2008), soil bulk density, and increases soil carbon and improves soil structure (Pinamonti *et al.*, 1995; Tiquia *et al.*, 2002). Mulching and green manuring are reliable and effective techniques to increase soil organic matter that help in soil replenishment, maintains soil fertility and moisture conservation. Green manuring and soil mulching play an important role in conservation of soil moisture during dry spell, besides decreasing water runoff and soil erosion (Hira *et al.*, 2003), in addition to increase water and fertilizer use efficiency (Salaria, 2009). Moreover, it helps in regulating soil temperature by keeping it warm in winter and cool in summer (Ramakrishna *et al.*, 2006). The application of organic and inorganic mulches creates an additive effect by restricting the nutrient removal through weeds and ultimately creating favorable conditions for availability of nutrients for getting higher productivity of good quality fruits on sustainable basis (Bakshi *et al.*, 2015).

Agriculture sector has transformed from sustainable to business-oriented enterprise and it has increased pressure on soil productivity, health and sustainability. Potential of organic amendments vary in different regions, which need to be carefully monitored (Sajjad *et al.*, 2018). The leguminous green manure (GM) crops are comparatively better than non- leguminous GM crops (Aynehband *et al.*, 2012). However, there is a need to investigate the potential of green manuring and mulching with conservation tillage (*i.e.* mulch with no-till) for wheat production and profitability under semiarid conditions. Conservation of soil moisture is imperative owing to meager costly irrigation facilities.

It is quite evident from the above review that issues of water resources management and soil health improvement as well as soil erosion are required to be addressed for arid and semi-arid agriculture. There is a dire need of rainfed areas to study economical methods for water conservation and improvement of soil health and productivity. Application of leguminous crops as GM and mulch is one of such economical methods. The present study was executed to evaluate the role of cowpea when used as "green manure" and "mulch with no till" in rainwater harvesting and increasing wheat productivity in Pothwar area of Pakistan.

# Material and methods

A field experiment was executed to study the role of cowpea (*Vigna unguiculata* L.) in rainwater harvesting and enhancing the wheat (*Triticum aestivum* L.) yield under rainfed conditions from 2014-15 to 2017-18. The experiment was conducted at the research area of Soil & Water Conservation Research Institute (SAWCRI) Chakwal, located at 32°55.756´ N latitude, 72°43.650´ E longitude with an altitude of 524 m. The climate of Chakwal is semi-arid, subtropical with hot summers and cold winters. The average rainfall of the area is 565 mm (http://climate-data.org). Weather data recorded at the meteorological observatory of SAWCRI, located within 1 km distance from the experimental site, were used. Detailed description of all data recorded with observations frequency is given in Table 1. Daily rainfall data was obtained from the SAWCRI observatory and estimated effective rainfall for the entire experimental duration (2014-2018). Rainfall events equal and above 5 mm were considered effective and showers below 5 mm were ignored. The experimental seasons generally comprise the months of July-August (for cowpea) and November-April (for wheat). However,

**Table 1.** Detail of data elements and their frequency of observation.

| Sr. No | Major data elements | Variables | Frequency of observation |
|---|---|---|---|
| 1. | Composite soil samples | Soil texture; organic matter; pH; ECe; available P; extractable K | At beginning of experiment |
| 2. | Rainfall | Water availability in the root zone | Fortnightly |
| 3. | Soil moisture (gravimetric method) | Water retention; water availability | **Before** wheat sowing<br>**After** 2 months of sowing; 4 months of sowing; at harvesting |
| 4. | Crop data of cowpea | Fresh biomass | After harvesting |
| 5. | Crop data of wheat | Plant population; fertile tillers; straw yield; and grain yield | Once in season after germination and after harvesting wheat crop |

actual dates of cowpea growth, its incorporation & decomposition, and wheat growth for each year and accordingly the monthly effective rainfall values are presented in Table 2.

Soil samples were collected down to the depths 0-15 cm and 15-30 cm from various random locations in the experimental field. Then, composite soil samples were prepared before execution of the experiment to study the physio-chemical characteristics of experimental field which are presented in Table 3. The soil samples were air dried and sieved prior to analysis. Particle size distribution (Bouyoucos, 1962), soil pH (McLean, 1982), ECe (USDA, 1954), organic matter (Walkley, 1947), available phosphorus (Olsen & Sommers, 1982) and extractable potassium (USDA, 1954) were analyzed.

Experiment was laid in a randomized complete block design with four replications and three treatments: T1 = control (conventional farmer's practice), T2 = cowpea sown after conventional tillage practices and incorporated in the soil to act as "green manure", and T3 = cowpea sown with no-tillage, cut with sickle and spread to use as "mulch with no-till". The size of each experimental plot was 19 m × 25 m. The conventional farmer's practice comprises one tillage with moldboard plow followed by repeated tillage with cultivator, then wheat seed is sown without mulch and GM.

**Table 2.** Growing cycles of cowpea and wheat along with effective rainfall, mean temperature and mean humidity.

| Weather variables | | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | Total rainfall (mm) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cowpea period | | Decomposition period | | Wheat period | | | | | | Cowpea period | Transition period | Wheat period |
| Rainfall (mm) | 2014-15 | 78.0 | 152.0 | 141.0 | 75.0 | 0.0 | 0.0 | 6.0 | 21.0 | 203.0 | 112.0 | 230.0 | 216.0 | 342.0 |
| | 2015-16 | 150.0 | 72.0 | 77.0 | 43.0 | 0.0 | 0.0 | 19.0 | 38.0 | 60.0 | 29.0 | 222.0 | 120.0 | 146.0 |
| | 2016-17 | 269.0 | 63.0 | 95.0 | 0.0 | 0.0 | 0.0 | 34.0 | 25.0 | 6.0 | 85.0 | 332.0 | 95.0 | 150.0 |
| | 2017-18 | 226.0 | 161.0 | 18.0 | 0.0 | 14.0 | 18.0 | 0.0 | 18.0 | 32.0 | 78.0 | 387.0 | 18.0 | 160.0 |
| Mean min temp (ºC) | 2014-15 | 23.2 | 22.8 | 20.3 | 14. 9 | 7.5 | 2.2 | 2.2 | 5.3 | 8.8 | 14.9 | | | |
| | 2015-16 | 23.6 | 22.5 | 21.3 | 14.5 | 8.6 | 4.5 | 2.3 | 4.4 | 10.7 | 13.7 | | | |
| | 2016-17 | 24.0 | 24.0 | 20.5 | 15.9 | 8.1 | 3.5 | 4.0 | 5.8 | 9.4 | 15.4 | | | |
| | 2017-18 | 23.6 | 24.6 | 21.6 | 14.2 | 7.6 | 2.3 | 0.9 | 5.1 | 11.4 | 15.8 | | | |
| Mean max temp (ºC) | 2014-15 | 33.6 | 32.2 | 32.7 | 30.0 | 29.9 | 19.9 | 16.9 | 18.0 | 19.9 | 29.2 | | | |
| | 2015-16 | 35.3 | 34.4 | 35.1 | 33.0 | 26.1 | 23.2 | 17.3 | 22.2 | 24.1 | 32.3 | | | |
| | 2016-17 | 34.0 | 34.4 | 34.4 | 33.1 | 24.1 | 20.6 | 15.4 | 21.0 | 25.7 | 31.5 | | | |
| | 2017-18 | 34.5 | 35.3 | 34.4 | 29.8 | 24.6 | 24.6 | 19.8 | 21.4 | 27.5 | 30.7 | | | |
| Mean humidity (%) | 2014-15 | 75.3 | 80.4 | 73.5 | 53.9 | 64.7 | 66.4 | 72.8 | 71.0 | 77.5 | 73.0 | | | |
| | 2015-16 | 72.4 | 71.5 | 66.2 | 58.8 | 60.7 | 67.2 | 83.8 | 72.9 | 76.5 | 59.0 | | | |
| | 2016-17 | 73.6 | 73.6 | 63.2 | 54.0 | 77.0 | 81.5 | 86.0 | 68.2 | 62.0 | 47.1 | | | |
| | 2017-18 | 69.0 | 71.4 | 63.8 | 58.4 | 60.7 | 72.8 | 65.1 | 63.9 | 61.7 | 53.0 | | | |

**Table 3.** Soil characteristics of the experimental field.

| Characteristics | Depth (cm) | Value |
|---|---|---|
| pH | 0-15 | 7.87 |
| | 15-30 | 7.78 |
| ECe (dS/m) | 0-15 | 0.48 |
| | 15-30 | 0.50 |
| Organic matter (%) | 0-15 | 0.53 |
| | 15-30 | 0.48 |
| Available P (mg/kg) | 0-15 | 4.80 |
| | 15-30 | 3.30 |
| Extractable K (mg/kg) | 0-15 | 88.00 |
| | 15-30 | 80.00 |
| Textural class | 0-15 | Sandy loam |
| | 15-30 | Sandy loam |

Wheat variety 'Chakwal-50' and cowpea variety 'Rawan-2003' were used in the current experiment.

Cowpea was sown between last week of June and 1st week of July, using seed at rate of 60 kg/ha under treatments T2 & T3. Under treatment T2, cowpea was crushed and incorporated into the soil with rotavator to act as “GM” during the last week of August, when cowpea attained the maximum biomass (*i.e.*, about 60 days after sowing). Under treatment T3 the cowpea was reaped with sickle and spread on the soil surface to act as a “mulch”. Biomass of cowpea was recorded at humidity levels of 80.4%, 71.5%, 73.6% and 71.4% during 2014, 2015, 2016, and 2017, respectively. Observations were recorded (thrice from each treatment with four replications) on fresh biomass production of cowpea at the time of incorporation and spreading as mulch. After the above activity, wheat (*Triticum aestivum* L.) seed pre-treated with 2 g/kg Topsin M was sown, using 125 kg/ha seed with row spacing of 22.5 cm between last week of October and first week of November under all three treatments. Mineral fertilizers were applied at 120-80-60 kg N-$P_2O_5$-$K_2O$ per hectare at the time of sowing as a basal dose and other agronomic practices were kept uniform in all treatments. On maturity wheat crop was harvested by manual reaping with sickle and threshing with mini thresher. All the pre-defined variables were recorded using standard procedures. Economic analysis of the experiment in terms of benefit-cost ratio (BCR) was carried out to study the net return from farmer’s perspective. All costs involved in carrying out the experiment and returns obtained from all of three treatments were recorded. The variable costs comprised the cost of tillage, cost of cowpea and wheat seed, laborer’s cost, cost of fertilizers, cost of weedicides etc. Prevailing market rates of wheat grains and its straw (*bhoosa*) were collected from local markets.

## Results and discussion

### Rain harvesting during cowpea growing period

Agriculture in Pothwar area mostly depends on rainfall, which is quite erratic with large temporal variations (Table 2). Monthly effective rainfall, actually available to crop and fresh biomass production of cowpea from both treatments (*i.e,* cowpea sown in tilled soil to be used as GM and cowpea sown without tillage to be used as mulch) were estimated (Fig. 1).

It was observed that biomass production of cowpea depends on effective rainfall as well as soil tillage. Figure 1 shows that there were less fresh biomass of cowpea under T3 (cowpea sown with no till practice) than under T2 (cowpea sown after conventional tillage) with the same amount of rainfall. Analysis of data revealed that biomass production under T2 and T3 was 15.20 t/ha and 13.72 t/ha, respectively, corresponding to the minimum

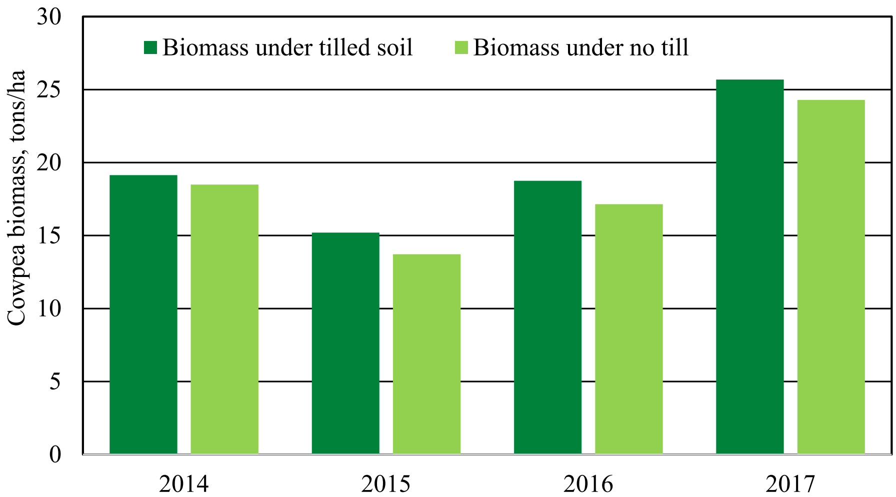


**Figure 1.** Biomass production of cowpea during the study period

effective rainfall of 222 mm during cowpea growth period 2015. Nevertheless, the maximum effective rainfall (387 mm) of cowpea growth period was observed in 2017 with biomass production of 25.69 t/ha and 24.21 t/ha under T2 and T3, respectively. It means biomass production of cowpea is highly dependent on rainfall during its growing season. Data of rainfall and biomass production revealed that biomass production under tilled land was 7% more as compared to no tilled land, which shows the vital role of tillage in rainwater harvesting for soil moisture storage. A similar trend of biomass production in relation to precipitation was also observed by Yan *et al.* (2015), which confirms the above results.

## Rainwater harvesting and soil water availability for wheat

Statistical analysis of data regarding available soil water showed a variable trend. At sowing of wheat, available soil water was 79, 80 and 78 mm/m under T2 and 76, 80 and 50 mm/m under T3, while in control it was 75, 80 and 75 mm/m during 2014-15, 2015-16 and 2016-17, respectively (Table 4). However, exceptional values of soil moisture were observed during 2017-18 (Table 5), which will separately be dealt with.

During the first two years of study, soil water was statistically at par among the treatments, while in 3rd year the trend was a bit different. It was observed that T3 statistically conserved less moisture (50 mm/m) as compared to green manuring (78 mm/m) and control (75 mm/m). Available mean soil water was maximum (79 mm/m) in green manuring treatment followed by control (77 mm/m) but the results were statistically non-significant and both treatments significantly improved available soil moisture as compared to mulching (69 mm/m). Green manuring of cowpea improved soil moisture retention and availability during the entire wheat growing periods. Table 4 also shows estimations of soil water availability during the wheat growing period at intervals of 2 months and 4 months after sowing as well as at harvesting. Although the soil water availability after 2 months of sowing and at harvesting was lower compared to that at sowing and after 4 months of sowing, this phenomenon is explained by the occurrence of rainfall during February and March. Sultani *et al.* (2007) and Sajjad *et al.* (2018) have also reported improvement in soil moisture by green manuring.

As explained above, the available soil moisture at all three intervals in 2017-18 was comparatively lower than that of other years (Table 5). This happened due to quite low rainfall during decomposition of GM compared to other years and available soil water was consumed for decomposition of biomass, thus less soil water was available. Rainfall occurred during March-April was eventually consumed by the thirsty crop. It is therefore concluded that rainfall occurrence from the start of decomposition period to one month after sowing plays vital role in soil water availability at various stages. Salahin *et al.* (2013) also reported that different GM crops improve soil moisture contents.

**Table 4.** Soil water availability at various time intervals.

| Treatments | 2014-15 | 2015-16 | 2016-17 | Mean | 2014-15 | 2015-16 | 2016-17 | Mean |
|---|---|---|---|---|---|---|---|---|
| | **Available water (mm/m) at sowing** | | | | **Available water (mm/m) after 60 days** | | | |
| T1 | 75 a | 80 a | 75 a | 77 A | 56 ab | 28 de | 40 cd | 41 B |
| T2 | 79 a | 80 a | 78 a | 79 A | 67 a | 46 bc | 45 bc | 53 A |
| T3 | 76 a | 80 a | 50 b | 69 B | 57 ab | 45 bc | 23 e | 42 B |
| Mean | 77 A | 80 A | 67 B | - | 60 A | 39 B | 36 B | - |
| | Critical value for comparison: Treatment & Year = 3.600, Interaction = 8.48 | | | | Critical value for comparison: Treatment & Year = 6.55, Interaction = 15.444 | | | |
| | **Available water (mm/m) after 120 days** | | | | **Available water (mm/m) at harvesting** | | | |
| T1 | 80 a | 80 a | 57 c | 72 B | 52 ab | 23 d | 33 cd | 36 AB |
| T2 | 80 a | 80 a | 67 b | 76 A | 56 a | 26 d | 40 bc | 41 A |
| T3 | 80 a | 80 a | 48 d | 69 C | 54 a | 26 d | 24 d | 35 B |
| Mean | 80 A | 80 A | 57 B | - | 54 A | 25 C | 32 B | - |
| | Critical value for comparison: Treatment & Year = 2.41, Interaction = 5.68 | | | | Critical value for comparison: Treatment & Year= 6.034, Interaction = 14.221 | | | |

Lowercase letters indicate significant differences among the values of interaction between treatments and years and different uppercase letter indicate significant differences between mean values of each column and row

**Table 5.** Effect of green manuring and mulching on available soil water (2017-18).

| Treatments | Available water (mm/m) | | | |
|---|---|---|---|---|
| | At sowing | After 02 months | After 04 months | At harvesting |
| T1 | 46 a | 69a | 32 a | 73 a |
| T2 | 12 c | 59 a | 26 a | 75 a |
| T3 | 22 b | 45 b | 28 a | 77 a |

Critical value for comparison: sowing = 6.048, 02 months = 12.701, 04 months = 8.9581, harvesting = 9.0596

Hence, the results revealed that available soil water can be linked with amount of effective rainfall and its distribution as well as the tillage practice. This phenomenon is in confirmation of Mosavi *et al.* (2012), who described that GM application has significant effects on water infiltration rate and available soil moisture. Rainwater harvesting and its in-situ conservation to be available for plants greatly depend upon the amount and temporal distribution of rainfall. Although the uniform temporal distribution of rainfall over the crop season plays a vital role, rainfall during decomposition (transition) period is the most important and effective for moisture availability when green manuring is applied. To study this effect, temporal distribution of rainfall was also noted by recording the quantities of rainfall per event and number of dry days between two events. Dry spells of each year are depicted in Fig. 2 and their effect can be seen in soil water availability as given in Table 4, which shows that soil water availability was the lowest in 2016-17 due to longest dry spell of 114 days and in 2017-18 due to comparative low rainfall (18 mm). This leads to the finding that GM may affect the soil moisture adversely if rainfall is low during decomposition period (Table 2). GM application in rotation with spring wheat requires more intensive management techniques than traditional fallow wheat system in rainfed conditions, as reported by Pikul *et al.* (1997) who further found that leguminous GM crops consumed more soil water, remaining thus the wheat yield unstable.

## Effect of harvested rainwater on wheat crop production

### *Plant population*

Plant population of wheat crop per square meter was recorded each year for each treatment as given in Table 6 and was studied in relation to rainwater harvested and store in the root-zone as soil water considering given treatments and rainfall distribution. Results showed that plant population is directly proportional to available soil water at sowing time and rainfall pattern, especially rainfall occurrence during cowpea decomposition. Among the three years, higher plant population of wheat was observed under T2 than under T3. The lowest plant population amongst the years and amongst the treatments was observed during 2016-17. On one hand, plant population increases with rainfall and subsequently soil water availability; on the other hand, it endorses the role of cowpea and tillage in rainwater conservation when used as GM, thus ultimately gives more plant population. These results verify the findings

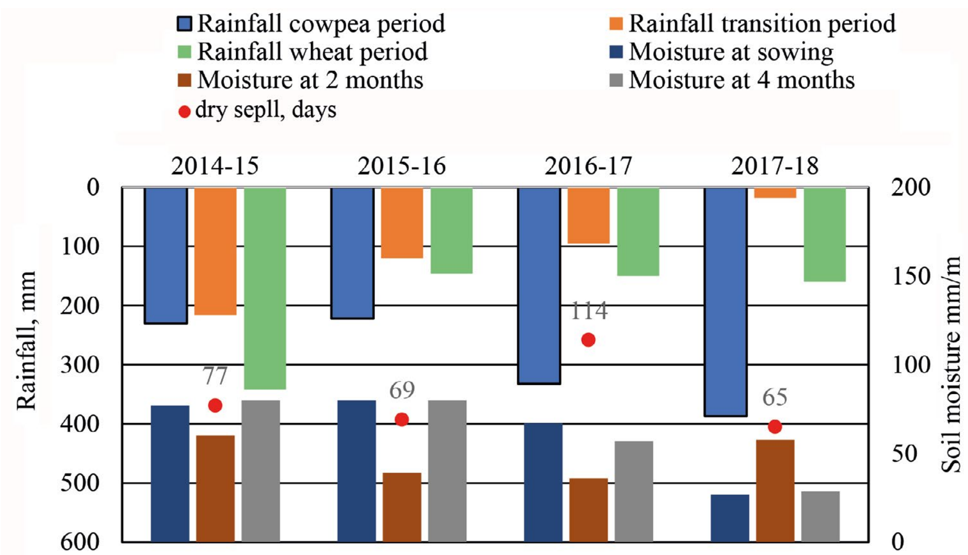


**Figure 2.** Effective rainfall during cowpea growing period vs. biomass production

**Table 6.** Effect of green manuring and mulching on various yield attributes of wheat.

| Treatments | 2014-15 | 2015-16 | 2016-17 | Mean | 2014-15 | 2015-16 | 2016-17 | Mean |
|---|---|---|---|---|---|---|---|---|
| | **Plant population/m²** | | | | **Fertile tillers/m²** | | | |
| T1 | 207 ab | 218 ab | 105 d | 178 A | 324 b | 405 a | 193 c | 307 A |
| T2 | 224 ab | 230 a | 109 d | 186 A | 333 b | 424 a | 195 c | 317 A |
| T3 | 199 bc | 175 c | 94 d | 156 B | 327 b | 350 b | 131 d | 269 B |
| Mean | 210 A | 208 A | 103 B | Mean | 328 B | 393 A | 173 C | - |
| | Critical value for comparison: Treatment =10.61, Year = 10.610, Interaction = 25.006 | | | | Critical value for comparison: Treatment =15.59, Year = 15.59, Interaction =36.74 | | | |
| | **Wheat straw yield (kg/ha)** | | | | **Wheat grain yield (kg/ha)** | | | |
| T1 | 6116 bc | 6387 bc | 5677 c | 6060 B | 3480 ab | 3672 a | 2789 c | 3314B |
| T2 | 7686 a | 6609 abc | 5691 c | 6662 A | 4068 a | 4072 a | 2890 bc | 3677 A |
| T3 | 7051 ab | 5532 c | 3588 e | 5390 C | 3835 a | 3064 bc | 1904 d | 2934 C |
| Mean | 6951 A | 6176 B | 4985 C | | 3794 A | 3603 A | 2528 B | |
| | Critical value for comparison: Treatment = 518.03, Year = 518.03 Interaction = 1220.9 | | | | Critical value for comparison: Treatment = 254.87, Year = 254.87, Interaction = 600.68 | | | |

Lowercase letters indicate significant differences among the values of interaction between treatments and years. Uppercase letters indicate differences between mean values of each column and row

of Podolsky (2013) who reported that the plant density of wheat was significantly affected by GM application. Similarly, Sajjad *et al.* (2018) observed a 4% increase in the plant population after the application of cowpea green manuring.

## *Productive tillers*

Productive tillers of wheat crop showed significant variation among years and small variation among treatments (Table 6). It was observed that maximum number of fertile tillers were observed during the year 2015-16 under T2, wherein rainfall was well distributed during wheat season with least dry spell during decomposition period; T3 produced significantly lower number of productive tillers (131) during 2016-17 when longest dry spell was observed. However, cowpea incorporation slightly (3.3%) increased the number of productive tillers, which confirms the results of Khan *et al.* (1996). Hoque *et al.* (2016) reported that *Sesbania aculeata* green manuring increased the number of effective tillers up to 7.5%. Similarly, Sajjad *et al.* (2018) also reported an increase of 7% in productive tillers by applying GM.

## *Straw yield*

Data on straw yield revealed significant variations during the first 3 years (Table 6). More straw yield was observed in cowpea incorporation as GM during all three years with the highest value (7686 kg/ha) in 2014-15. Green manuring of cowpea improved straw yield as compared to control and mulching with no-till. It was observed that straw yield was largely affected by available moisture at sowing as well as during 3rd and 4th months. These results are in line with findings of Sultani *et al.* (2004) who observed an increase of 16% in total wheat biomass by using *S. aculeata* as GM. Above results also confirm the findings of Zhang *et al.* (2013), who reported that incorporation of leguminous GMs enables the soil to harvest the rain water and increases soil water use efficiency in dry land system. Sajjad *et al.* (2018), reported an increase of 14% in biomass production of wheat by using GMs.

## *Grain yield*

It was observed that T2 produced higher grain yield to the tune (17%, 11% and 4% during 2014-15, 2015-16 and 2016-17, respectively) as compared to control (Table 6). T3 resulted in 10% higher yield during the year 2014-15 (3835 kg/ha) as compared to control (3480 kg/ha). However, T3 resulted in yield reduction of 17%, 32% and 23% respect to control during 2015-16, 2016-17 and 2017-18, respectively. It means tillage is also an important factor in conserving the moisture as was also indicated by Kováč *et al.* (2005), who reported that tillage with moldboard plough resulted in more soil moisture content than reduced till, mulch till and no-till treatments. Thus, T2 is a better option for enhancing wheat productivity and ensuring soil health in rainfed conditions of Pothwar plateau as compared to fallow-wheat (T1) and cowpea mulching with no- till (T3). Results of current study confirms the findings of Yadav *et al.* (2003), who reported a similar trend of improved crop growth and yield by GM application. GMs from leguminous crops improve crop yield through improvement in soil conditions and nutrient status (Shah *et al.*, 2011). Hoque *et al.* (2016) reported that application of GM significantly increases the yield of wheat. Bai *et al.* (2017) and Sajjad *et al.* (2018) reported an improved crop growth and yield by GM application. The average maize grain yield was 22% higher as compared to the control when GM was applied (Yang *et al.*, 2018).

### Exceptional results

Analysis of data on various crop yield attributes for the last year (2017-18) showed quite contrary results as compared to first three years (Table 7). It was observed that crop yield attributes *i.e.*, plant population (105 plants/m$^2$), productive tillers (179 tillers/m$^2$), straw yield (2880 kg/ha) and grain yield (1563 kg/ha) under green manuring were the least among all three treatments during the last year.

These exceptional results of green manuring were due to very low rainfall during the decomposition of cowpea and during the first 2 months, thus the existing soil moisture was consumed for decomposition of green biomass during decomposition period. Since there was very low rainfall (18 mm), soil moisture was very low at the time of wheat sowing and no further rainfall was received, this resulted in very low soil moisture and thus in a poor wheat crop. This finding leads to the fact that green manuring is only beneficial if rainfall occurs during decomposition period, otherwise negative results are expected. So, the forecast of next three months at the time of sowing of leguminous crops for GM must be used for decision-making. Therefore, climatic factors need to be carefully observed for evaluating the effects of green manuring on crop productivity. Some negative results have also been earlier reported by Pikul *et al.* (1997). He reported 25% reduction in wheat yield with GM application as it consumed more soil water and unstable wheat production. Hence, soil water use efficiency under GM applications in comparison with fellow cropping system, particularly in rainfed parts of the world, must be carefully evaluated.

### Cost and return analysis

Total costs, returns along with net returns are depicted in Fig. 3. The cost of treatments slightly varied during four years of experimentation, while return varied a lot. During the first two years the highest return of all treatments were those from T2, but in the third year return from all treatments reduced due to moisture shortage. During the 4$^{th}$ year net return was negative from T2 treatment due to the reason above described. The overall data revealed that incorporation of cowpea as GM gave higher net profit in wheat production than T3 and control (without cowpea) treatments. Green manuring of cowpea increased the net profitability up to 13%, provided that rainfall occurs in time, while in case of T3 the profitability was reduced to 24% as compared to control (Fig. 4).

Fig. 4 shows that BCR of all treatments was >1, except T2 during 2017-18. It means all treatments are feasible and T2 is the most profitable treatment (with BCR=1.8) which conserves moisture as well as improves the soil health by providing organic matter and additional N with exception mentioned above. The results also highlighted the potential of rainfed agriculture of Pothwar. Kumar *et al.* (2011) found that GM application resulted in higher BCR and net return through increased productivity and less labor expenses. Similarly, Fabunmi *et al.* (2012) reported 78% higher returns from maize crop through cowpea GM. Hirpa (2013) observed an increased dry matter and grain yield in the subsequent maize crop and highest net benefits with the incorporation of cowpea. Above findings are also in line with Mooleki *et al.* (2016), who concluded that GM is practicable and viable as compared to summer fallowing. Fertilizer use can be reduced 15–30% of recommended dose through GM treatment (Yang *et al.*, 2018).

## Conclusions

It is concluded that cowpea incorporation has the potential to harvest rainfall, conserve soil moisture and improve soil health, ultimately increasing the wheat productivity in rainfed conditions. Mulching of cowpea with no tillage is not a sustainable option to enhance wheat productivity as negative trends were observed.

**Table 7.** Effect of green manuring and mulching on wheat yield attributes (2017-18).

| Treatments | Grain yield (kg/ha) | Straw yield (kg/ha) | Plant population/m$^2$ | Fertile tillers/m$^2$ |
|---|---|---|---|---|
| T1 | 2404 a | 4294 a | 110 a | 204 a |
| T2 | 1563 c | 2880 b | 105 a | 179 b |
| T3 | 1849 b | 3328 b | 108 a | 186 b |
| Critical value for comparison: grain =239.08, straw = 471.37, plant population = 6.6263, tillers = 11.437 | | | | |

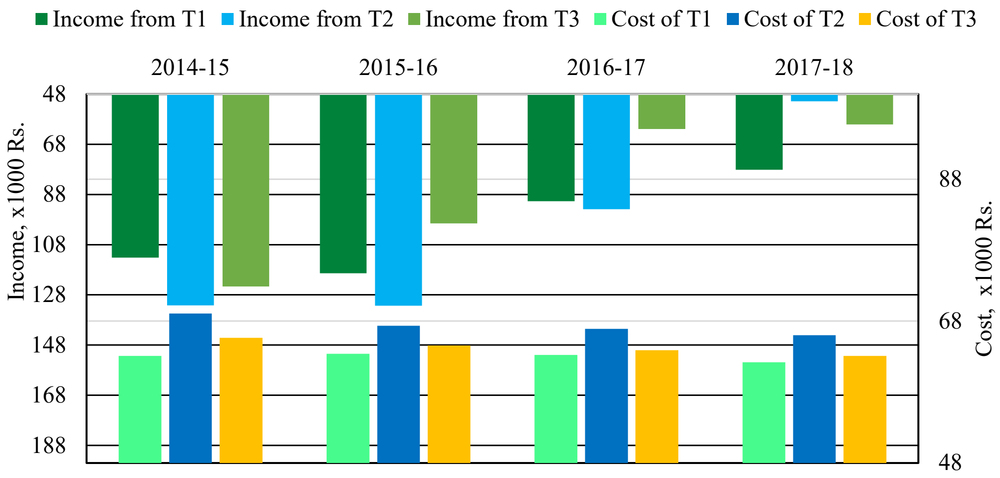


**Figure 3.** Comparison of cost and return for treatments

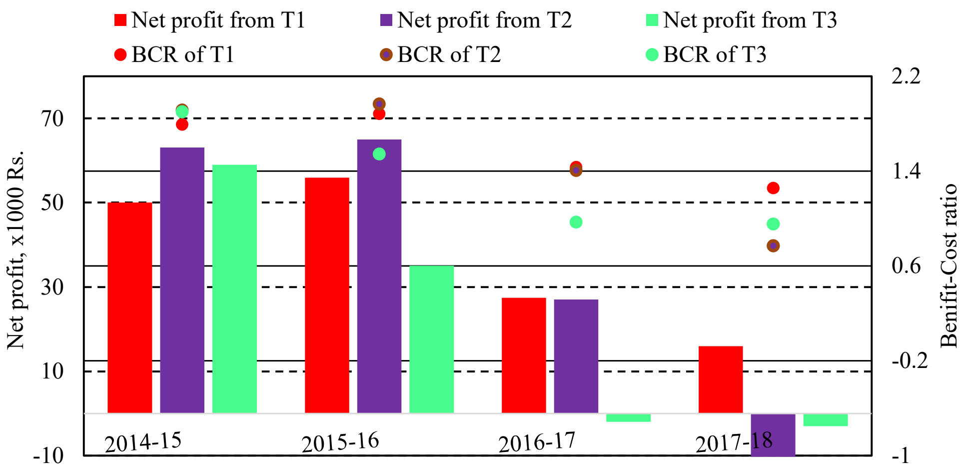


**Figure 4.** Net return and benefit-cost ratio (BCR) of all treatments

However, wheat productivity by green manuring and mulching largely depends on rainfall distribution/pattern and hence available soil water. The experimental results highlight that rainfall pattern and distribution during the growth period and critical stages are more reliable indicators, as soil water availability is essentially needed during entire growth period. GM of cowpea seems to be useful and effective for growth and development of succeeding wheat crop, provided appropriate rainfall is received. Furthermore, exceptional trends revealed that GM would not perform better as compared to control and mulch with no-till if prolonged dry periods prevail. Hence, it is concluded that climate change is a key factor affecting wheat crop productivity under semi-arid conditions of Pothwar plateau.

Considering the above findings, especially the exceptional results obtained during 2017-18, it is suggested that cowpea should be used as green manure for longer periods and results should be investigated for sustainability of agricultural system in rainfed conditions. In addition to this, mulch with till may be studied in different agro-ecological zones in future for establishing a comprehensive understanding of green manuring and mulching. Climatic and environmental effects on wheat productivity must be further investigated.

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## References

Aynehband A, Gerami F, Fateh E, 2012. Effect of different green manure crops and nitrogen levels on biomass production efficiency and nitrogen concentration in wheat (*Triticum aestivum* L.) and soil. Adv Environ Biol 6 (1): 362-367.

Bai Y, Zuo W, Yan Y, Gu C, Guan Y, Mei L, Xue W, Shan Y, Feng K, 2017. Sewage sludge amendment combined with green manuring to a coastal mudflat salt-soil in Eastern China: Effects on soil physicochemical properties and maize yield. Int J Agron: art ID 8526598. https://doi.org/10.1155/2017/8526598

Bakshi P, Wali VK, Iqbal M, Jasrotia A, Kour K, Ahmed R, Bakshi M, 2015. Sustainable fruit production by soil moisture conservation with different mulches: A review. Afr J Agr Res 10 (52): 4718-4729. https://doi.org/10.5897/AJAR2014.9149

Blanco H, Lal R, 2008. Soil and water conservation. Principles of soil conservation and management, Springer, the Netherlands.

Bouyoucos GJ, 1962. Hydrometer method improved for making particle-size analysis of soils. Agron J 53: 464-465. https://doi.org/10.2134/agronj1962.00021962005400050028x

Dick RP, 1992. A Review: long-term effects of agricultural systems on soil biochemical and microbial parameters. Agr Ecosyst Environ 40: 25-36. https://doi.org/10.1016/B978-0-444-89390-1.50005-6

Evanylo G, Sherony C, Spargo J, Starner D, Brosius M, Haering K, 2008. Soil and water environmental effects of fertilizer-, manure, and compost- based fertility practices in an organic vegetable cropping system. Agr Ecosyst Environ 127: 50-58. https://doi.org/10.1016/j.agee.2008.02.014

Fabunmi TO, Agbonlahor MU, Odedina JN, Adigbo SO, 2012. Profitability of pre-season green manure practices using maize as a test crop in a derived savanna of Nigeria. Pak J Agr Sci 49 (4): 593-596. https://doi.org/10.5539/jas.v4n7p57

Hanjra MA, Qureshi ME, 2010. Global water crisis and future food security in an era of climate change. Food Policy 35: 365-377. https://doi.org/10.1016/j.foodpol.2010.05.006

Hira L, Rao VK, Singh VP, 2003. Effects of various mulches on growth and yield of apple cv. Starching Delicious orchard. Prog Hort 35 (1): 100-103.

Hirpa T, 2013. Effect of stage at termination of legume green manures on soil organic carbon, yield and economic performance of subsequent maize crop. Int J Curr Res Acad Rev 1 (2): 84-101.

Hoque TS, Akhter F, Islam MR, 2016. Residual effects of different green manures on the growth and yield of wheat. As J Med Biol Res 2 (4): 624-630. https://doi.org/10.3329/ajmbr.v2i4.31006

IPCC, 2007. Climate change: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the International Panel of Climate Change. Cambridge University Press, UK. pp: 29-45.

Khan PK, Musa M, Shahzad MA, Aadat NK, Nasim M, 1996. Wheat performance on green manured and fertilized fields. Pak J Soil Sci 11 (1-2): 84-86.

Kováč K, Macak M, Švančárková M, 2005. The effect of soil conservation tillage on soil moisture dynamics under single cropping and crop rotation. Plant Soil Environ 3: 124-130. https://doi.org/10.17221/3564-PSE

Kumar N, Mina BL, Chandra S, Srivastva AK, 2011. In-situ green manuring for enhancing productivity, profitability and sustainability of upland rice. Nutr Cycl Agroecosys 90 (3): 369. https://doi.org/10.1007/s10705-011-9438-0

Marris E, 2008. More crop per drop: Nature 452 (7185): 273-278. https://doi.org/10.1038/452273a

McLean EO, 1982. Soil pH and lime requirement. In : Methods of soil analysis, Part 2: Chemical and microbiological properties; Page AL (ed.), pp: 199-224. Am Soc Agron, Madison, WI, USA. https://doi.org/10.2134/agronmonogr9.2.2ed.c12

Milly PCD, Betancourt J, Falkenmark M, Hirsch RM, Kundzewicz ZW, 2008. Climate change - Stationarity is dead: Whither water management? Science 319: 573-574. https://doi.org/10.1126/science.1151915

Mooleki SP, Gan Y, Lemke RL, Zentner RP, Hamel C, 2016. Effect of green manure crops, termination method and stubble crops, and fallow on soil water, available N, and exchangeable P. Can J Plant Sci 96 (5): 867-886. https://doi.org/10.1139/cjps-2015-0336

Mosavi SB, Jafarzadeh AA, Nishabouri MR, Ostan S, Feiziasl V, Karimi E, 2012. The effect of different green manure application in dry land condition on some soil physical properties. SB Int J Agr and Crop Sci 4: 1233-1239.

Olsen SR, Sommers LE, 1982. Phosphorus. In: Methods of soil analysis, Part 2: Chemical and microbiological properties, 2nd ed., Page AL (ed.), pp: 403-430. Am Soc Agron, Madison, WI, USA. https://doi.org/10.2134/agronmonogr9.2.2ed.c24

Pikul JL, Aase JK, Cochran, VL, 1997. Lentil green manure as fallow replacement in the semiarid northern Great Plains. Agron J 89 (6): 867-874. https://doi.org/10.2134/agronj1997.00021962008900060004x

Pinamonti F, 1998. Compost mulch effects on soil fertility, nutrition status and performance of grapevine. Nutr Cycl Agro Ecosys 51: 239-248. https://doi.org/10.1023/A:1009701323580

Pinamonti F, Zorzi G, Gasperi F, Silvestri S, 1995. Growth and nutritional status of apple trees and grapevine in municipal solid-waste-amended soil. Acta Hortic 383: 313-321. https://doi.org/10.17660/ActaHortic.1995.383.32

Podolsky K, 2013. Reduced tillage implements for management of an organic green manure: Effects on nitrogen, weeds, and wheat yield. MSc thesis, Univ of Manitoba, Winnipeg.

Ramakrishna A, Tam HM, Wani SP, Long TD, 2006. Effect of mulch on soil temperature, moisture, weeds infestation and yield of groundnut in northern Vietnam. Field Crop Res 95: 115-125. https://doi.org/10.1016/j.fcr.2005.01.030

Rashid K, Saleh S, Naurin K, 2012. Weather and wheat crop development in Potohar Region Punjab (Rawalpindi) (2015-2016). Regional Agromet Centre Pakistan Meteorological Department Shamsabad, UAAR Rawalpindi, Pakistan.

Rockstrom J, Karlberg L, Wani SP, Barron J, Hatibu N, 2010. Managing water in rainfed agriculture-The need for a paradigm shift. Agr Water Manage 97: 543-550. https://doi.org/10.1016/j.agwat.2009.09.009

Sajjad MR, Subhani A, Rafique R, Hussain T, Naseem W, Bibi R, Malik SN, 2018. Green manuring for moisture conservation and wheat yield improvement in rainfed agriculture. J Nat Sci Res 8: 33-41. https://doi.org/10.19045/bspab.2019.80095

Salahin N, Alam MK, Islam MM, Naher L, Majid NM, 2013. Effects of green manure crops and tillage practice on maize and rice yields and soil properties. Aust J Crop Sci 7 (12): 1901.

Salaria A, 2009. Horticulture at a glance. Handbook for Competitive Exams, Vol 2. Jain Brothers, East Park Road Karol, Bagh, New Delhi, pp: 34-235.

Salma S, Rehman S, Shah MA, 2012. Rainfall trends in different climate zones of Pakistan. Pak J Meteorol 9 (17): Jul 2012.

SAWCRI, 2020. Annual Research Report, 2020. Soil and Water Conservation Research Institute, Chakwal.

Shah Z, Ahmad SR, Rahman HU, Latif A, Shah A, 2011. Rice and wheat yields in relation to biomass of green manure legumes. Sarhad J Agric 27 (1): 73-84.

Sultani MI, Gill MA, Anwar MM, Athar M, 2007. Evaluation of soil physical properties as influenced by various green manuring legumes and phosphorus fertilization under rain fed conditions. Int J Environ Sci Technol 4 (1): 109-118. https://doi.org/10.1007/BF03325968

Sultani MI, Shouka M, Mahmood IA, Joyia MF, 2004. Wheat growth and yield response to various green manure legumes and different P levels in Pothowar region. Pak J Agri Sci 41 (3-4): 102-108.

Tiquia SM, Lloyed J, Herms DA, Hoitink HAJ, 2002. Effects of mulching and fertilization on soil nutrients, microbial activity and rhizosphere bacterial community structure determined by analysis of TRFLPs of PCR amplifications 16S rRNA genes. Appl Soil Ecol 21: 31-48. https://doi.org/10.1016/S0929-1393(02)00040-9

Trisdal JM, 1989. Soil management. Acta Hortic 240: 161-168. https://doi.org/10.17660/ActaHortic.1989.240.29

USDA, 1954. Diagnosis and improvement of saline and alkali soils. United States Salinity Laboratory Staff. USDA Handbook 60. Washington, DC. pp: 89-91.

Walkley A, 1947. A critical examination of a rapid method for determining organic carbon in soils: Effect of variations in digestion conditions and of organic soil constituents. Soil Sci 63: 251-263. https://doi.org/10.1097/00010694-194704000-00001

WWAP, 2009. The 3rd United Nations World Water Development Report: Water in a Changing World. World Water Assessment Programme. UNESCO, Paris, and Earthscan, London.

Yadav RL, Singh VK, Dwivedi BS, Shukla AK, 2003. Wheat productivity and N use-efficiency as influenced by inclusion of cowpea as a grain legume in a rice-wheat system. J Agr Sci 141 (2): 213-220. https://doi.org/10.1017/S0021859603003563

Yan H, Liang C, Liu Z, Li Z, Miao B, He C, Sheng L, 2015. Impact of precipitation patterns on biomass and species richness of annuals in a dry steppe. PLoS ONE 10 (4): 1-14. e0125300. https://doi.org/10.1371/journal.pone.0125300

Yang L, Bai J, Liu J, Zeng N, Cao W, 2018. Green manuring effect on changes of soil nitrogen fractions, maize growth, and nutrient uptake. Agronomy 8 (11): 261. https://doi.org/10.3390/agronomy8110261

Zhang DB, Yao PW, Li J, Zhao N, Wang Z, Yu CW, Cao QH, Cao WD, Gao YJ, 2013. Effects of two years decomposition of leguminous green manure on soil properties of a wheat field in dryland conditions. Acta Ecologica Sinica 33 (7): 2272-2281. https://doi.org/10.5846/stxb201112261981