

## Rapeseed Yield in a Maize – Rapeseed Cropping Pattern over a Long-Term Nutrient Management Experiment

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### ABSTRACT

A long-term soil fertility experiment in maize (*Zea mays*) – rapeseed (*Brassica campestris* var. toria) cropping system was initiated in Nepal Agricultural Research Council (NARC), Directorate of Agricultural Research (DoAR), Lumbini Province, Banke, Khajura (the then Regional Agricultural Research Station) since 1994. The field experiment was designed in the randomized complete block including nutrient as treatment at nine rates (0–0–0 nitrogen – phosphorus – potash (N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O) kg/ha, 60–0–0 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha, 60–40–0 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha, 60–40–20 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha, 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha, 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + 30 cm stover from previous maize, 60–40–20 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + 30 cm stover from previous maize, farmyard manure 10 t/ha and 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + farmyard manure 6 t/ha) and was replicated three times. Rapeseed crop yield attributes including days to flowering, plant height, siliqua per plant, 1000 grains weight, seed yield and straw yield and soil fertility parameters including soil pH, soil organic matter content, soil total nitrogen content, soil available phosphorus content and soil available potash content were monitored from 1994 to 2018 growing seasons. There was a significant effect ( $p < 0.01$ ) of nutrient treatments in the days to flowering, plant height, siliqua per plant, 1000 grains weight, seed yield and straw yield. The highest mean seed yield (445 kg/ha) was obtained from the nutrient application at the rate of 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + farmyard manure 6 t/ha during 1994 – 2018. Yield trend analysis revealed nutrient treatment with farmyard manure both FYM 10 t/ha and 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + FYM 6 t/ha had significant positive ( $p < 0.001$ ,  $R^2 > 0.30$ ) trend of rapeseed seed yield with the maximum 1000 kg/ha rapeseed yield in 2018. Soil analysis results after rapeseed harvest in 2018 showed two nutrient treatments including farmyard manure had significant high soil organic matter (SOM > 1%), soil available phosphorus content (P<sub>2</sub>O<sub>5</sub> > 55 kg/ha) and soil available potash content (K<sub>2</sub>O > 550 kg/ha). In the long-term, integrated nutrient management applying 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + FYM 6 t/ha was the optimal nutrient management option for rapeseed production in maize – rapeseed cropping system at Khajura and similar agro-ecological conditions.

**Keywords:** Integrated plant nutrient management, maize – mustard cropping system, mustard, *tori*, yield prediction

### सारांश

मकै – तोरी बाली प्रणालीमा दिर्घकालीन माटोको उर्वराशक्ति परिक्षण अनुसन्धान वि.सं. २०५१ सालबाट कृषि अनुसन्धान निर्देशनालय, लुम्बिनी प्रदेश, बाँके, खजुरा (तत्कालिन क्षेत्रीय कृषि अनुसन्धान केन्द्र)मा शुरू भएको हो। यो अनुसन्धानको संरचना नियन्त्रण नरहेको पूर्ण ब्लक (RCBD) अन्तर्गत विरुवाको खाद्यतत्व मिश्रणको नौवटा परिक्षण (०–०–० नाईट्रोजन–फोस्फरस–पोटास (ना–फा–पो) केजी/हेक्टर, ६०–०–० ना–फा–पो केजी/हेक्टर, ६०–४०–० ना–फा–पो केजी/हेक्टर, ६०–४०–२० ना–फा–पो केजी/हेक्टर, ३०–२०–१० ना–फा–पो केजी/हेक्टर, ३०–२०–१० ना–फा–पो केजी/हेक्टर + ३० सेमी ढोड अधिल्लो मकैबाट, ६०–४०–२० ना–फा–पो केजी/हेक्टर + ३० सेमी ढोड अधिल्लो मकैबाट, गोठेमल १० टन/हेक्टर, ३०–२०–१० ना–फा–पो केजी/हेक्टर + गोठेमल ६ टन/हेक्टर) लाई तीनपटक दोहोच्याएर गरिएको हो। तोरीको वि.सं. २०५१ देखि २०७५ सालसम्मको बालीको उत्पादन सम्बन्धित आधारहरू (फूल फुल्ल लाग्ने दिन, विरुवाको उचाई, विरुवामा कोसाको संख्या, १००० तोरीको दानाको तौल, तोरीको उत्पादन/हेक्टर र तोरीको नलको उत्पादन/हेक्टर) र माटोको जाँच नतिजा (पी.एच., प्रांगारिक पदार्थको मात्रा, जम्मा नाइट्रोजनको मात्रा, फोस्फरसको मात्रा, पोटासको मात्रा) सम्बन्धी संकलित

तथ्यांकहरूको विश्लेषण गरी यो पत्र तयार गरिएको छ। विभिन्न खाद्यतत्वहरूको परिक्षणले फूल फुल लाग्ने दिन, विरुवाको उचाई, विरुवामा कोसाको संख्या, एक हजार दानाको तौल, तोरीको उत्पादकत्व र तोरीको नलको उत्पादकत्वमा गणितीय हिसाबमा फरक देखिएको छ। अहिलेसम्मको नतिजाले ३०-२०-१० नाईट्रोजन-फोस्फरस-पोटास (ना-फा-पो) केजी/हेक्टर + गोठेमल ६ टन/हेक्टरका दरको तरिकामा औसत सबभन्दा बढी तोरी (४४५ केजी/हेक्टर) फलेको पाइयो। विगत वर्षहरूको तोरीको उत्पादनको विश्लेषण गर्दा गोठेमल राखिएका दुवै परीक्षणहरू गोठेमल १० टन/हेक्टर एवं ३०-२०-१० ना-फो-पो केजी/हेक्टर + गोठेमल ६ टन/हेक्टरका दरले गरिएको खाद्यतत्व व्यवस्थापनमा हालका वर्षहरूमा तोरीको उत्पादकत्व गणितीय हिसाबमा बढीरहेको र वि.सं. २०७५ सालमा सबभन्दा बढी १००० केजी/हेक्टर तोरी फलेको देखिन्छ। वि.सं. २०७५ को माटो परीक्षणको नतिजाले गोठेमल राखिएका दुवै परीक्षणमा माटोमा प्रांगारिक पदार्थको मात्रा (१% भन्दा बढी), फोस्फरसको मात्रा (५० केजी/हेक्टर भन्दा बढी) र पोटासको मात्रा (५५० केजी/हेक्टर भन्दा बढी) गणितीय हिसाबमा फरक देखिएको छ। दिर्घकालिन परीक्षणको नतिजा हेर्दा खजुरा र सो सरहका आवहवामा ३०-२०-१० ना-फो-पो केजी/हेक्टर र गोठेमल ६ टन/हेक्टरका दरको गरिने खाद्यतत्व व्यवस्थापन नै मकै – तोरी बाली प्रणालीअन्तर्गत तोरीको उत्पादन गर्न उपयुक्त खाद्यतत्व व्यवस्थापनको उपाय हुने देखिन्छ।

## INTRODUCTION

Rapeseed (*Brassica campestris* var. toria) also known as black mustard or tori is the number one oilseed crop in Nepal (Thakur 2014). It is grown in the winter season (September – March) after paddy or maize (NORP 2017). After paddy (*Oryza sativa*) – wheat (*Triticum aestivum*), maize (*Zea mays*) – rapeseed cropping system is the dominant cropping system in Nepal (Thakur and Khadka 2004). This system is mainly followed in the rainfed areas (Ghimire et al 2012). Oilseed crops are cultivated in a 260,307 ha area and annual production is 280,530 mt (AITC 2020). Being a cash crop, the decline in rapeseed productivity has caused negative impacts on the farming livelihoods and economy of the country (Sharma 2019). Imbalanced or no fertilization practice is one of the reasons for the declined rapeseed productivity (Mishra and Chaudhary 2010).

Farmyard manure (FYM) is the only plant nutrient supplied for rapeseed cultivation in the traditional subsistence farming systems in Nepal (Karki et al 2004). Farmyard manure is a well-decomposed mixture of animal manure and crop residue collected from animal shed, containing essential plant nutrients (Chaudhary and Narwal 2004). The official recommended dose of FYM for rapeseed is 6 t/ha (AITC 2020). However, due to the limited availability of FYM, rapeseed is grown without any addition of nutrients from external sources causing declined rapeseed productivity (Malla et al 2015).

In pursuit of increasing rapeseed yield, after the green revolution, chemical fertilizers containing essential macro-nutrients nitrogen (N), phosphorus (P, expressed as  $P_2O_5$ ) and potash (K, expressed as  $K_2O$ ) at the rate of 60–40–20 N– $P_2O_5$ – $K_2O$  kg/ha was recommended for rapeseed cultivation in Nepal (AITC 2020, Shrestha 2010). Ojha et al (2018) found no significant increase on rapeseed yield with nitrogen dose more than 60 kg/ha along with 40–20  $P_2O_5$ – $K_2O$  kg/ha in Chitwan district, Nepal. Neupane et al (1997) reported 'Bikash' variety of rapeseed with the fertilizer dose of 80–60–40 N– $P_2O_5$ – $K_2O$  kg/ha and obtained rapeseed seed 500 kg/ha in Dhankuta district, Nepal. Chaudhary et al (2004) found in addition to 60–40–20 N– $P_2O_5$ – $K_2O$  kg/ha, application of sulfur at the rate of 20 kg/ha produced a significantly higher rapeseed yield (1200 kg/ha) in the farmers' field experiment in Chitwan and Sarlahi districts, Nepal. In addition to N, P and K nutrients, application of sulfur can contribute to rapeseed yield (Malla et al 2015, Thapa 2006).

Despite the application of chemical fertilizers for rapeseed production, soil fertility decline due to low soil organic matter content is one of the main reasons for declining rapeseed yield in Nepal (Karki et al 2004, Ghimire et al 2012). Soil organic matter is the reservoir of the plant nutrients, maintain soil physical, chemical, and biological properties for plant growth and development (Kononova 2013). Along with the application of organic manures including FYM, incorporation of crop residue from a preceding crop is recommended for maintaining soil organic matter content (Lehtinent et al 2014). Crop residue incorporation is also known to increase the rapeseed yield along with soil fertility improvement (Karki et al 2014, Paudel 1997). For example, maize residue kept in the field has boosted rapeseed yield by 15 kg/ha in the farmers' field experiment in Palpa district, Nepal (Karki et al 2014). Besides, incorporating green manure intercropped in maize increased rapeseed yield by 200 kg in Chitwan district, Nepal (Paudel 1997). Soil organic matter improvement can increase or maintain the rapeseed productivity in the long-term (Abdullah, 2014).

While maintaining soil productivity, climatic variables like rainfall and temperature influence rapeseed productivity (O'Neill et al 2019, Jaime et al 2018). In the context of climate change, changes in the winter temperature can influence rapeseed yield (O'Neill et al 2019). For rapeseed production, the optimum temperature for germination is 21 – 25°C but not more than 30°C and rainfall of 250 – 400 mm is enough (Booth and Gunstone 2004, Ghimire 2013). The long-term yield studies provide uniform data to analyse the effect of climatic variables.

Continuous cultivation of the same crops and nutrient management practices year after year results in change in the crop yield attributes and soil fertility parameters (Maltas et al 2018, Macdonald et al 2018, Regmi et al 2002). For the quantitative analysis of such practices, long-term soil fertility experiments in maize – rapeseed cropping system were established in National Maize Research Program (NMRP), Rampur, Chitwan district in 1992 (Srivastava and Neupane 1998) and in Directorate of Agricultural Research, Lumbini Province, Khajura, Banke district (the then Regional Agricultural Research Station) in 1994. In the Rampur, Chitwan condition Srivastava and Neupane (1997) found irrespective of the treatments, the yield trends of both maize and rapeseed were declining over that period (1992 – 1996). To address the problem of yield decline in the agricultural lands with maize – rapeseed cropping pattern and identical nutrient management continuously, this study present findings from a maize – rapeseed long-term experiment conducted in the mid-western terai of Nepal. The objectives of this study were 1) to find out the optimal nutrient management practice for rapeseed cultivation in maize – rapeseed cropping system, 2) to compare the change in the soil fertility in the long-term, 3) to analyze the effect of maize stover incorporation on rapeseed yield and soil fertility and 4) to assess the effect of rainfall and temperature on rapeseed yield.

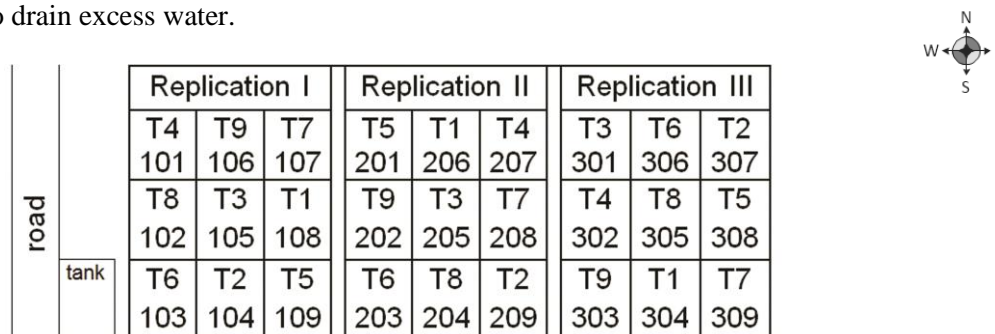
## MATERIALS AND METHODS

### Location

A long-term experiment in maize – rapeseed cropping system was initiated in 1994 in Nepal Agricultural Research Council (NARC), Directorate of Agricultural Research (DoAR), Lumbini Province, Khajura, Banke district of Nepal (the then Regional Agricultural Research Station). The experimental block is located at 28°6'52.12" north (latitude) and 81°35'33.738" east (longitude) in mid-western terai at 181 masl. In the research station, average annual temperatures are minimum 5.4°C and maximum 46°C with an annual rainfall of 1000 – 1500 mm (RARS Khajura 2016). Soils in the research station are sandy to silty loam in texture (RARS Khajura 2016).

### Experimental design and treatments

The field layout of the long-term experiment designed in a randomized complete block (Figure 1). Each plot size was 27 m<sup>2</sup> with at least 20 cm thick bund between the plots to prevent water inflow from one plot to another. For irrigation, furrows were dug between plots from west to east. This research block was situated in a place where flooding can be avoided through the northern boundary to drain excess water.



**Figure 1.** Field layout of a maize – rapeseed long-term experiment at DoAR, Lumbini Province, Banke, Khajura.

Nutrient as treatment at nine rates were included in the long-term experiment (Table 1) and replicated three times. Treatment with no external nutrient inputs of N, P and K (0–0–0 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha) gives the idea of soil nutrient supplying capacity to compare with the effect of other treatments with nutrient addition. Application of 60–40–20 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha was the recommended chemical fertilizer dose for the rapeseed cultivation (Mishra and Chaudhary 2010). Application of farmyard

manure (FYM) 10 t/ha as a treatment before each crop in maize – rapeseed cropping system gives an idea of the effect of organic rapeseed production in the long duration. As a source of FYM, a goat farm in the station was the regular source. Conservation agriculture technique of crop residue incorporation was included in two treatments with 30 cm maize stover addition. In those two treatment plots, 30 cm maize stover from the same plot were mixed in the soil after maize harvest.

**Table 1. Nutrient treatments in a maize – rapeseed long-term experiment at DoAR, Lumbini Province, Banke, Khajura.**

Treatment symbols	Maize (N–P <sub>2</sub> O <sub>5</sub> –K <sub>2</sub> O kg/ha)	Rapeseed (N–P <sub>2</sub> O <sub>5</sub> –K <sub>2</sub> O kg/ha)
T1	00–00–00	00–00–00
T2	120–00–00	60–00–00
T3	120–45–00	60–40–00
T4	120–45–45	60–40–20
T5	60–30–30	30–20–10
T6	60–30–30 + rapeseed straw	30–20–10 + 30 cm stover from previous maize
T7	120–45–45 + rapeseed straw	60–40–20 + 30 cm stover from previous maize
T8	FYM 10 t/ha	FYM 10 t/ha
T9	60–30–20 + FYM 6 t/ha	30–20–10 + FYM 6 t/ha

### Cropping calendar

Available data on the cropping calendar of rapeseed in different years of the long-term experiment in maize – rapeseed cropping system is presented in Table 2. The median duration between maize stover incorporation and land preparation for rapeseed sowing was 31 days (Table 2). In October, the land was ploughed to fine tilth using human power following the conventional tillage method (Table 2). The full dose of P and K, and half dose of N was applied as a basal dose during land preparation as per nutrient treatments. Similarly, farmyard manure (FYM) was applied as a basal dose. After fine tilth, rapeseed was sown in lines at 30 cm distance.

**Table 2. Rapeseed cropping calendar in a maize – rapeseed long-term experiment at DoAR, Lumbini Province, Banke, Khajura (1994 – 2018).**

Year	Maize stover incorporation date	Variety	Sowing date	Harvesting date	Remarks
1994					No information on dates and varieties
1995					
1996					
1997					
1998					Only seed yield data in 1997
1999					No information on dates and varieties
2000	25 Jul 2000	Bikash	18 Oct 2000	15 Jan 2001	
2001	14 Sept 2001	Bikash	3 Oct 2001	25 Dec 2001	
2002	8 Oct 2002	Bikash	15 Oct 2002	6 Jan 2003	
2003	23 Sept 2003	Bikash	12 Oct 2003	14 Jan 2004	
2004	21 Aug 2004	Pragati	27 Oct 2004	28 Jan 2005	
2005	19 Sept 2005	Pragati	30 Oct 2005		
2006	20 Sept 2006	Pragati	16 Oct 2006	27 Jan 2007	
2007	5 Sept 2007	Bikash	9 Oct 2007	29 Dec 2007	
2008	19 Jun 2008	Bikash	16 Oct 2008	20 Jan 2009	
2009		Bikash	30 Oct 2009	25 Jan 2009	
2010					No data available in 2010
2011		Bikash	21 Oct 2011	31 Jan 2012	
2012					No data available in 2012
2013		Bikash	2 Nov 2013	6 Mar 2014	
2014		Pragati	19 Oct 2014	16 Jan 2015	
2015	4 Sept 2015	Unnati	5 Oct 2015	24 Feb 2016	
2016	31 Aug 2016	Unnati	10 Nov 2016	9 Feb 2017	
2017	10 Sept 2017	Unnati	11 Oct 2017	5 Jan 2018	
2018	28 Aug 2018	Unnati	24 Sept 2018	16 Dec 2018	

Thinning was accomplished within two weeks of germination. One-fourth of the N fertilizer dose was applied after thinning and the remaining N fertilizer before flowering as per treatment. Irrigation

applied at least after thinning before applying N fertilizer, before the second top dressing and at the start of flowering. On average, rapeseed was harvested after 90 days after sowing (Table 2).

In Table 2, for the years without any recorded data on the date of maize stover incorporation, a variety used, sowing date, and harvesting date, they are left blank. Only seed yield data was available in 1997. No data on crop yield attributes were available in the years 2010 and 2012.

### Data collection on rapeseed yield attributes

Rapeseed yield attributes including days to flowering, plant height (cm), siliqua per plant, 1000 grains weight (g), seed yield (kg/ha) and straw yield (kg/ha) were measured. Days to flowering is the duration between rapeseed sowing and first initiation of the flowering determined observing the plant growth continuously. For plant height and siliqua per plant, randomly selected five plants from each plot were measured and averaged. Plant height was measured from ground level to the tip of the longest branch using a one-meter measuring scale. The number of siliqua per plant was determined by adding all the siliqua in a plant. Thousand grains weight was calculated by weighing counted dried seeds from five siliqua per plant from randomly selected five plants in each plot. Dried seed weight and straw weight from each plot were converted to kg/ha.

### Soil chemical analyses

Topsoil (0 – 30 cm depth) three sub-samples from each plot were taken before land preparation for rapeseed sowing and after harvest of rapeseed. Soil samples were air-dried and ground to sub-2 mm. Soil samples were analysed for soil pH, organic matter content, total nitrogen content, available phosphorus content and available potash content.

For soil pH measurement, a 3.0 g soil was mixed in calcium chloride (0.01 M CaCl<sub>2</sub>) solution (Houba et al 2000) and measured in a soil pH meter (Thermo, Orion 2 Star, pH benchtop). Organic matter was determined using 0.5 g sub-0.5 mm sieved soil following a modified Walkley Black titration method (FRSRD 1980). Total nitrogen content was determined using 1.0 g soil following the Kjeldahl digestion and titration method (FRSRD 1980). Soil available phosphorus was extracted using 2.5 g soil in sodium bicarbonate (0.5 N NaHCO<sub>3</sub>) solution (FRSRD 1980) to analyze in a spectrophotometer (Gensys 10s uv-vis). Soil available potassium was extracted using 5.0 g soil in ammonium acetate (1 M CH<sub>3</sub>COONH<sub>4</sub>) solution (Ryan et al 2001) to analyze in a flame photometer (Esico, model 1381).

Soil sample analysis results were only available for 1996 before maize in the maize – rapeseed long-term experiment (Table 3). The soil analysis results showed soil pH was neutral (7.3), organic matter content was low (1.34%), total nitrogen content was low (0.067%), available phosphorus content was low (P<sub>2</sub>O<sub>5</sub> 56.6 kg/ha) and available potash content was medium (K<sub>2</sub>O 161.3 kg/ha) (Table 3) as per the ratings fixed by NARC, National Soil Science Research Center (SSD 2017).

**Table 3. Soil fertility status before maize in a maize – rapeseed long-term experiment at DoAR, Lumbini Province, Banke, Khajura in 1996 (mean).**

Treatments (N– P <sub>2</sub> O <sub>5</sub> – K <sub>2</sub> O kg/ha)	Soil pH	Organic matter (%)	Total nitrogen (%)	Available phosphorus (P <sub>2</sub> O <sub>5</sub> ) kg/ha	Available potash (K <sub>2</sub> O) kg/ha
00–00–00	7.3	1.13	0.056	63.5	143.8
60–00–00	7.4	1.86	0.093	27.5	168.4
60–40–00	7.3	1.28	0.062	73.8	139.3
60–40–20	7.2	1.55	0.077	75.5	156.3
30–20–10	7.2	1.14	0.057	58.4	188.4
30–20–10 + 30 cm stover	7.2	1.22	0.061	85.8	171.1
60–40–20 + 30 cm stover	7.4	1.49	0.075	32.6	152.6
FYM 10 t/ha	7.1	1.43	0.071	46.4	168.4
30–20–10 + FYM 6 t/ha	7.3	0.99	0.050	46.3	163.2
<b>Mean</b>	<b>7.3</b>	<b>1.34</b>	<b>0.067</b>	<b>56.6</b>	<b>161.3</b>



### Meteorological data

Weather data since February 1995 was available from the meteorological station established by the Department of Hydrology and Meteorology (DHM), in the NARC, DoAR, Banke, Khajura. The temperature and rainfall data were gathered for the cropping season (September – February) from 1995 – 2018. The daily mean temperature was calculated taking an average of 8:45 am and 5:45 pm minimum and maximum temperatures.

### Data analyses

The R statistical environment (R Core Team 2020) was used to analyze data. R packages ‘agricolae’ (de-Mendiburu 2020), ‘raster’ (Hijmans 2020) and ‘psych’ (Revelle 2020) were used to differentiate the level of significance ( $p < 0.05$ ,  $< 0.01$  and  $< 0.001$ ) of nutrient treatments on yield attributes and soil fertility parameters, to determine mean, coefficient of variation (CV) and standard error (SE) respectively. Tukey’s highly significant difference (HSD) values were determined for the significantly different effect of nutrient treatments on crop yield and soil fertility parameters. Best fit models were developed first using linear and two-degree polynomial functions. Graphs were drawn using R packages ‘ggplot2’ (Wickham et al 2019b) and ‘tidyverse’ (Wickham et al 2019a).

## RESULTS

### Growth and yield attributes

Rapeseed growth and yield attributes were significantly ( $p < 0.01$ ) influenced by the nutrient treatments compared to the control treatment (Table 4). Three nutrient treatments, 60–40–20 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha with or without 30 cm maize stover and 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + FYM 6 t/ha performed statistically similar in plant height (72 – 73 cm), 1000 grains weight (3 g), seed yield (435 – 445 kg/ha) and straw yield (1225 – 1551 kg/ha) (Table 4). Days to flowering was the earliest (30 days after seeding) with the application of FYM 10 t/ha followed by nutrient treatment with 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + FYM 6 t/ha (Table 4). Siliquae per plant (51 – 52) was similar in nutrient treatment with 60–40–0 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha, 60–40–20 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + 30 cm maize stover and 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + FYM 6 t/ha (Table 4).

**Table 4.** Rapeseed agronomic performance in a maize – rapeseed long-term experiment at DoAR, Lumbini Province, Banke, Khajura (1994 – 2018) (mean ± SE).

Treatments (N– P <sub>2</sub> O <sub>5</sub> – K <sub>2</sub> O kg/ha)	Plant height (cm)	Days to flowering	Siliqua per plant	1000 grains weight (g)	Seed yield (kg/ha)	Straw yield (kg/ha)
00–00–00	52.9 ± 1.9	36 ± 0	28 ± 5	2.76 ± 0.06	133.05 ± 14.87	358.8 ± 35.4
60–00–00	65.1 ± 1.7	35 ± 0	37 ± 4	2.78 ± 0.06	275.59 ± 30.60	804.0 ± 95.5
60–40–00	69.7 ± 1.8	32 ± 0	51 ± 6	2.90 ± 0.07	389.58 ± 34.20	1303.0 ± 139.2
60–40–20	71.9 ± 1.8	33 ± 0	45 ± 5	3.09 ± 0.07	435.94 ± 35.09	1551.0 ± 144.9
30–20–10	66.2 ± 1.9	33 ± 1	36 ± 4	2.90 ± 0.08	359.86 ± 35.40	941.7 ± 93.8
30–20–10 + 30 cm stover	67.9 ± 1.9	34 ± 1	37 ± 4	2.99 ± 0.06	348.22 ± 35.80	952.0 ± 94.8
60–40–20 + 30 cm stover	72.5 ± 1.8	33 ± 1	52 ± 6	3.01 ± 0.06	439.55 ± 49.47	1308.0 ± 129.3
FYM 10 t/ha	66.7 ± 2.2	30 ± 0	40 ± 5	3.04 ± 0.07	392.99 ± 38.33	748.2 ± 72.2
30–20–10 + FYM 6 t/ha	73.0 ± 2.0	31 ± 0	51 ± 6	3.03 ± 0.07	445.24 ± 31.80	1225.0 ± 94.8
CV (%)	20.9	1.9	85.6	13.4	80.9	67.6
p value	< 0.001	< 0.001	< 0.01	< 0.01	< 0.001	< 0.001
Tukey’s HSD value	8.5	2	22	0.29	185.6	459.8

CV = coefficient of variation, HSD = Highly significant difference; ns = non-significant

### Rapeseed yield trend

The trend analysis of nutrient treatments effect on rapeseed yield from 1994 – 2018 period is shown in Figure 2 and Table 5. In the initial years of the long-term experiment, rapeseed yield ranged from 700 – 2000 kg/ha (Figure 2). Rapeseed yield declined in all the treatments in the subsequent years, irrespective of the treatments applied (Figure 2). Between 2000 – 2010, there was a little change in the yield trend (Figure 2). After that, some treatments started to increase rapeseeds yield including treatments with farmyard manure (FYM 10 t/ha or 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + FYM 6 t/ha) (Figure 2).

The rapeseed yield was 700 kg/ha in the first year of the experiment in control treatments (0–0–0 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha) (Figure 2). The rate of yield decline was 10 times each year without the application of any chemical fertilizer (Figure 2, Table 5). When N chemical fertilizer (60–0–0 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha) was added as a nutrient source, 300 kg rapeseed production increased from a hectare of land compared to control plots at the start of the experiment (Figure 2). During 1994 – 2018, the application of only full dose of N fertilizer (60–0–0 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha) resulted in a higher yield decline compared to control plots (Figure 2, Table 5).

In addition to N, application of P chemical fertilizer (60–40–0 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha) produced a higher rapeseed yield to 1600 kg/ha in the first year of the long-term experiment (Figure 2). The yield decline in the subsequent years was lesser in nitrogen and phosphorus treatments compared to only nitrogen applied plots (Figure 2, Table 5). Using a combination of N, P, and K chemical fertilizers (60–40–20 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha) produced rapeseed yield of 1700 kg/ha during the initial years of the long-term experiment (Figure 2, Table 5). The yield decline was higher compared to only N and P fertilizer application in the subsequent years (Figure 2, Table 5).

Application of half dose of the recommended chemical fertilizer dose (30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha) produced 1400 kg rapeseed/ha in the first year of the long-term experiment (Figure 2, Table 5). The rate of yield decline in this treatment (30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha) was lesser than recommended chemical fertilizer dose of all three nutrients (60–40–20 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha) application in the subsequent years (Figure 2, Table 5).

There was a higher yield decline rate in the 30 cm maize stover incorporated two treatments (60–40–20 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + 30 cm maize stover and 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + 30 cm maize stover) than without maize stover (Figure 2, Table 5). There was a 10 times faster decline in seed yield in maize stover included treatments each year than nutrient only treatments (Figure 2, Table 5).

Both farmyard manure included treatments (FYM 10 t/ha and 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + FYM 6 t/ha) showed a decline in the initial years (1994 – 2010) of the long-term experiment as others (Figure 2, Table 5). After 15 years of experiment, higher rapeseed yields were trending in both treatments compared to other treatments (Figure 2, Table 5). Both treatments crossed maximum rapeseed yield 1000 kg/ha in 2018 (Figure 2).

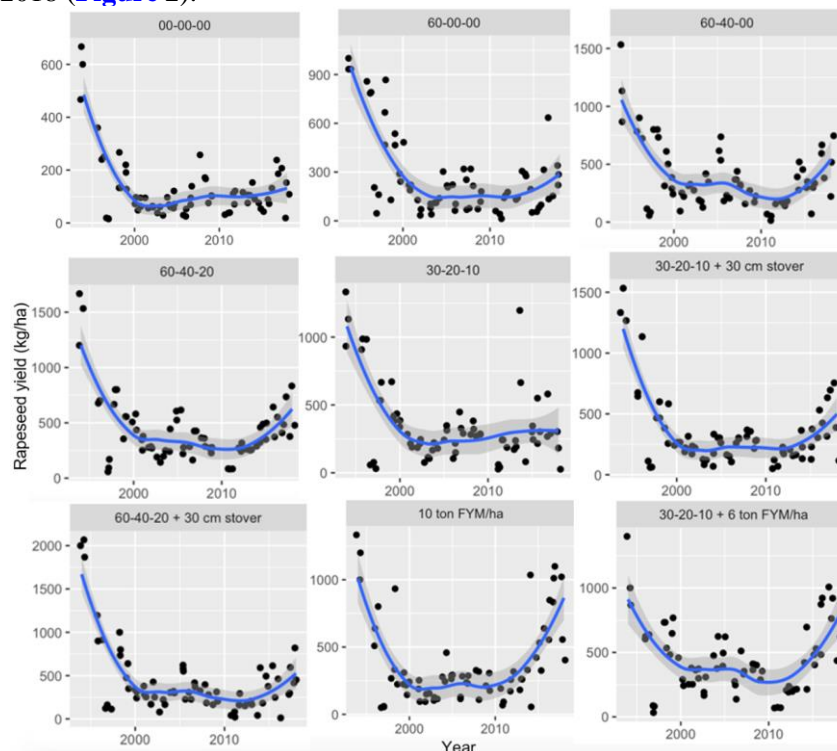


Figure 2. Rapeseed yield (kg/ha) in a maize – rapeseed long-term experiment at DoAR, Lumbini Province, Banke, Khajura (1994 – 2018).

**Table 5.** Best fit model of the rapeseed yield (y) pattern in different nutrient treatments during the number of years (x) in a maize - mustard long-term experiment at DoAR, Lumbini Province, Banke, Khajura (1994 – 2018).

Treatments (N–P <sub>2</sub> O <sub>5</sub> –K <sub>2</sub> O kg/ha)	Adjusted R <sup>2</sup>	p value
00–00–00	0.19	< 0.05
60–00–00	0.35	< 0.001
60–40–00	0.09	< 0.01
60–40–20	0.13	< 0.01
30–20–10	0.06	< 0.05
30–20–10 + 30 cm stover	0.23	< 0.001
60–40–20 + 30 cm stover	0.14	< 0.01
FYM 10 t/ha	0.54	< 0.001
30–20–10 + FYM 6 t/ha	0.32	< 0.001

### Soil fertility

There was a significant ( $p < 0.001$ ) effect of nutrient treatments on soil organic matter content, available phosphorus content and available potash content after rapeseed harvest in 2018 (Table 6). Farmyard manure included treatments (FYM 10 t/ha and 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + FYM 6 t/ha) showed significantly higher amount of soil organic matter content (SOM > 1.00%), available phosphorus content (P<sub>2</sub>O<sub>5</sub> > 50 kg/ha) and available potash content (K<sub>2</sub>O > 550 kg/hg) compared to other treatments (Table 6). Application of full dose of nitrogen fertilizer only treatment (60–0–0 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha) resulted in the least available phosphorus content (P<sub>2</sub>O<sub>5</sub> 15 kg/ha) (Table 6). Soil organic matter contribution due to stover included nutrient treatments were not significantly different compared to same nutrient treatments excluding maize stover (Table 6). Nutrient treatments had no significant effect on soil pH and total nitrogen content (Table 6).

**Table 6.** Soil fertility status after rapeseed harvest in a maize – rapeseed long-term experiment at DoAR, Lumbini Province, Banke, Khajura in 2018 (mean ± SE).

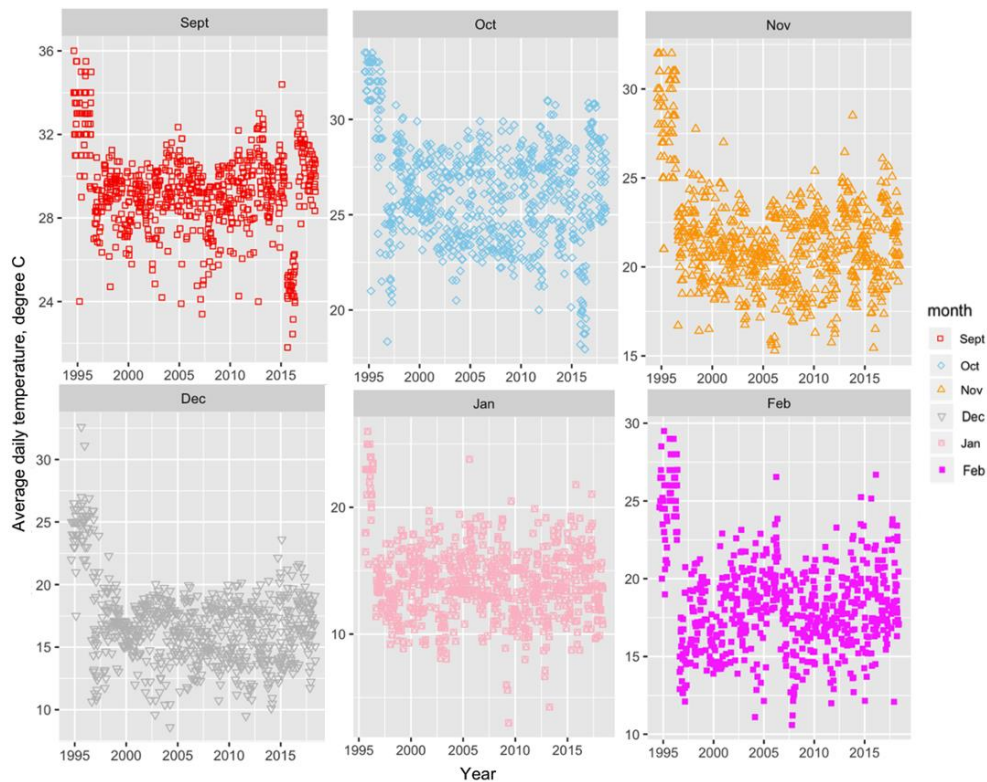
Treatments (N–P <sub>2</sub> O <sub>5</sub> –K <sub>2</sub> O kg/ha)	Soil pH	Organic matter (%)	Total nitrogen (%)	Available phosphorus (P <sub>2</sub> O <sub>5</sub> ) kg/ha	Available potash (K <sub>2</sub> O) kg/ha
00–00–00	6.4 ± 0.0	0.31 ± 0.23	0.015 ± 0.01	24.8 ± 13.0	78.8 ± 17.3
60–00–00	6.3 ± 0.1	0.28 ± 0.01	0.012 ± 0.01	15.3 ± 6.6	78.9 ± 12.0
60–40–00	6.5 ± 0.1	0.26 ± 0.04	0.014 ± 0.00	32.3 ± 3.0	103.0 ± 6.7
60–40–20	6.4 ± 0.1	0.22 ± 0.12	0.010 ± 0.00	31.3 ± 11.4	111.0 ± 9.5
30–20–10	6.1 ± 0.0	0.58 ± 0.22	0.013 ± 0.01	33.6 ± 8.9	106.7 ± 8.7
30–20–10 + 30 cm stover	6.1 ± 0.3	0.44 ± 0.08	0.017 ± 0.00	41.6 ± 15.1	246.4 ± 9.1
60–40–20 + 30 cm stover	6.4 ± 0.1	0.47 ± 0.00	0.020 ± 0.01	40.0 ± 18.8	274.8 ± 8.5
FYM 10 t/ha	6.4 ± 0.1	2.50 ± 0.33	0.019 ± 0.00	71.6 ± 16.3	565.3 ± 3.7
30–20–10 + FYM 6 t/ha	6.5 ± 0.1	1.13 ± 0.03	0.018 ± 0.00	56.2 ± 15.5	579.4 ± 8.0
CV (%)	3.35	114.16	51.91	56.01	98.98
p value	ns	< 0.001	ns	< 0.001	< 0.001
Tukey's HSD value		0.72		34.9	251.4

CV = coefficient of variation, HSD = Highly significant difference; ns = non-significant

### Rainfall and temperature effects on rapeseed yield

During the cropping season from 1995 to 2018, September was the hottest month with a maximum of 36°C (Figure 3). The coldest month was January with a minimum of 0.5°C (Figure 3).





**Figure 3.** Daily average temperature (°C) from September to February at DoAR, Lumbini Province, Banke, Khajura weather station (1995 – 2018).

There was a significant effect ( $p < 0.05$ ) of rainfall from September to December on rapeseed yield (Table 7). During the rapeseed growing season, on an average 150 to 200 mm rainfall contributed better yield (Table 7). From the regression analysis, September and November rainfall showed a significant ( $p < 0.01$ ) positive ( $R^2 > 0.10$ ) effect on rapeseed yield (Table 7). Twenty-three-year data analysis revealed 1 mm November rainfall can add 10 kg rapeseed yield (Table 7).

**Table 7.** September to December onthly rainfall (mm) effect on rapeseed yield in a maize – rapeseed long-term experiment at DoAR, Lumbini Province, Banke, Khajura (1995 – 2018).

Month	Adjusted $R^2$	p value
September	0.15	< 0.001
October	0.03	< 0.05
November	0.20	< 0.01
December	0.10	< 0.01

From 1995 to 2018, during the cropping season, September received the highest amount of monthly rainfall (165 mm) and the least monthly rainfall was in November (13 mm) (Figure 4). The mean six months total rainfall was 265 mm with the highest in 2014 (444 mm) and the least six-monthly total rainfall was in 2001 (96.5 mm) (Figure 4).



**Figure 4.** Daily rainfall amount (mm) during September to February at DoAR, Lumbini Province, Banke, Khajura weather station (1995 – 2018).

The average daily temperature from September to January had a significant positive effect ( $p < 0.001$ ) on the rapeseed yield (Table 8). From the regression analysis, November, and December temperature had a significant positive ( $R^2 > 0.30$ ) effect on rapeseed yield (Table 8).

**Table 8.** September to January monthly average temperature ( $^{\circ}\text{C}$ ) effect on rapeseed yield in a maize – rapeseed long-term experiment at Lumbini Province, Banke, Khajura (1995 – 2018).

Month	Adjusted $R^2$	p value
September	0.17	< 0.001
October	0.28	< 0.001
November	0.32	< 0.001
December	0.35	< 0.001
January	0.19	< 0.001

## DISCUSSION

### Effect of nutrient treatments on rapeseed yield

In this study, the long-term analysis (1994 – 2018) of rapeseed yield showed recommended dose of chemical fertilizers (60–40–20 N– $\text{P}_2\text{O}_5$ – $\text{K}_2\text{O}$  kg/ha) including all three macro-nutrients N, P and K produced higher rapeseed yield compared to nutrient treatments omitting either P or K (Table 4) highlighting the importance of balanced fertilization for obtaining good yield (Marschner 2012, Yousaf et al 2017). However, in the long-term, even a balanced dose of chemical fertilizers produced lesser yield compared to integrated nutrient management including half the recommended dose of chemical fertilizers and FYM (30–20–10 N– $\text{P}_2\text{O}_5$ – $\text{K}_2\text{O}$  kg/ha + FYM 6 t/ha) (Figure 2) highlighting the importance of organic manure for maintaining soil productivity (Maltas et al 2018). Farmyard manure being a source of micro-nutrients (including sulfur) along with improving soil physical, biological and chemical properties (Cho et al 2017, Karki et al 2004) contributed to the higher rapeseed yield in the long-term. To increase the rapeseed yield, integrated nutrient management including a balanced dose of N, P and K chemical fertilizers and organic manure can be both environmentally and economically viable way to fulfil the demand of the present population without degrading the quality of soil for future generations (Wu et al 2020, Devkota et al 2018).

### Soil fertility changes in the long-term

In this study, we compared the soil fertility status in 1996 and 2018 (Table 3 and 6). Soil pH decreased in 2018 compared to 1996 (Table 3 and 6) in all treatments including control treatments which was maybe due to strong organic acids produced by rapeseed roots for extracting nutrients from soils (Hoffland 1991). Application of nitrogen fertilizer may have also caused the soil pH decrease (Matlas et al 2018). Soil organic matter content was maintained or increased in the FYM included treatments (FYM 10 t/ha and 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + FYM 6 t/ha) in the long-term experiment (Table 3 and 6). In contrast to Matlas et al (2018), in the chemical fertilizers only treatments, organic matter content declined during 24 years of experiment in the tropical climate reaching 40°C during summer (RARS Khajura 2016) where carbon mineralization is rapid removing soil carbon when not applied from an external source (Wang et al 2013). Soil total nitrogen content was declined in all the treatments compared to the initial condition (Table 3 and 6). Historically, the research site being a natural grassland, it might have accumulated higher total nitrogen before initiation of the long-term experiment. In this study, with the loss of organic matter from the soil, nitrogen content in the soil has also declined (Kononova 2013). Soil available phosphorus content was maintained, and soil available potash content was increased in the FYM included treatments (Table 3 and 6). Phosphorus and potash content in the FYM prepared from goat manure have contributed to maintain both nutrients (Cho et al 2017). Soil available phosphorus content was the lowest in the nitrogen only treatment due to higher proportionate uptake of phosphorus from the soil for plant growth and development (Reich and Oleksyn 2004). Organic manure (eg FYM) application is vital for maintaining soil productivity for rapeseed production in the long-term (Matlas et al 2018).

### Effect of maize stover incorporation on rapeseed yield and soil fertility

In contrast to Karki et al (2014) and Das et al (2017), this study did not find any increase in rapeseed yield in the 30 cm maize stover incorporation added two nutrient treatments (Table 4). In contrast to Saha and Ghosh (2013), this study did not find any significant contribution of maize stover included treatments in the soil organic matter content when compared between 1996 and 2018 (Table 6). One of the reasons can be this study did not use whole maize stalk as mulch compared to the other studies (Karki et al 2014, Das et al 2017, Saha and Ghosh 2013). Rapeseed yield in the nutrient treatment with crop residue in addition to chemical fertilizers showed the effect of chemical fertilizers only. Rather yield obtained in the later years were lesser in crop residue incorporated nutrient treatments compared to nutrient treatments without maize stover (Figure 2). The incorporation of a smaller quantity of maize stover biomass (30 cm length), a short gap between maize harvesting and rapeseed sowing (median less than 5 weeks, Table 2) may have caused such disparity. Incorporation of maize stover in the soil was not able to decompose in such a short gap due to sub-tropical dry and hot climate (Figure 3 and 4) during that interval period (Johnson et al 2007). Hence, nutrients that could have been used for the plant growth were used for maize stover decomposition (Johnson et al 2007) resulted in a higher yield decline rate in maize stover included nutrient treatments than without maize stover (Lehtinen et al 2014). The shorter duration between maize harvest and rapeseed sowing (Table 2) was due to the requirement of early sowing of rapeseed to escape disease and pests damage (Ghimire et al 2012, Sharma 1997). To include maize stover as a nutrient management technology, using whole maize stalk as a mulch and following a conservation agriculture practice can be beneficial for rapeseed production (Karki et al 2014).

### Effect of rainfall and temperature on rapeseed yield

Analysis of 23 years of climate data showed a significant effect of rainfall and temperature on rapeseed yield (Table 7 and 8). In this study, the effect of the temperature was more pronounced on rapeseed yield than the rainfall (Table 7 and 8) due to the availability of irrigation facility in the research block. The decline in the post-monsoon rainfall in the coming years (DHM 2017) may have a negative effect on rapeseed yield in rainfed rapeseed growing areas (Ghimire et al 2012). In agreement with our results, O'Neill et al (2019) found a positive effect of winter temperatures on rapeseed yield. With predicted increase in winter temperature (DHM 2017) due to climate change may increase rapeseed yield in the coming years.

## CONCLUSIONS

This study presented 24 years experimental findings on rapeseed yield under maize – rapeseed cropping system established in 1994 in mid-western terai of Nepal. The long-term experiment was designed in the randomized complete block including nutrients as treatment at nine rates and replicated three times. Compared to recommended chemical fertilizer dose, treatment including both chemical fertilizers and farmyard manure (FYM) at the rate of 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + FYM 6 t/ha produced comparable rapeseed yield in addition to a positive yield trend in the recent years. Soil analysis results in 2018 showed two treatments including farmyard manure (FYM 10 t/ha and 30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + FYM 6 t/ha) contributed to the significant improvement in the soil organic matter content, soil available phosphorus content and soil available potash content compared to other treatments without farmyard manure. Integrated nutrient management (30–20–10 N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg/ha + FYM 6 t/ha) was the optimal treatment for rapeseed cultivation in maize – rapeseed cropping system maintaining both soil fertility and rapeseed yield in the long-term. On using maize stover as a nutrient treatment, using whole maize stalk as a mulch and following a conservation agriculture practice can be beneficial for rapeseed production and soil fertility maintenance than the current practice of 30 cm stover incorporation from previous maize following a conventional agriculture practice. Continuity of the long-term experiments monitoring soil fertility parameters including additional soil physical, biological, and chemical parameters can guide the future soil fertility management strategies for rapeseed production in a maize – rapeseed cropping system in Khajura and similar agro-ecological zones.

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