Environmentally sound alternative cropping systems for rice–wheat systems in North West India

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Received: 21 May 2021 / Accepted: 17 January 2022
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Abstract
Continuous cultivation of rice–wheat cropping system (RWCS) in Indo-Gangetic Plains of India is showing declining factor productivity coupled with many environmental problems. Diversifying the RWCS is one of the environmental friendly options for sustaining food production. Four crop rotations involving maize and sorghum in summer, wheat/potato/mustard in winter followed by short duration mung bean in late spring were studied to identify the most productive and economic combination from 2017 to 2020. Ranking of treatments by Tukey’s test of significance indicated that the maize-potato-wheat (16.49 t ha⁻¹ year⁻¹) combination was best in terms of system productivity calculated in terms of wheat equivalent yield (WEY). Maize-wheat-mung bean crop sequence was most profitable by having higher land use efficiency (LUE = 87.67%) and net return (NR = 1577.1 $ ha⁻¹). The gross margin comparison revealed that maize-based crop sequences earned higher gross returns (23.17%), net return (93.66%), and B:C ratio (23.7%) than sorghum-based crop sequences. Soil health parameters were improved under the maize-mustard-mung bean system, which increased the organic carbon content by 28.65%, available N by 34.91% with saving of 47.67% in irrigation water. Adoption of alternate cropping sequences instead of rice–wheat, in the Indo-Gangetic Plains of India, could be more sustainable, profitable, and environment friendly.

1 Introduction
The rice–wheat cropping system is the principal crop production system in South Asia and occupies approximately 13.5 million hectares’ area of which a majority of 10.3 million hectares is in India (Ladha et al. 2000; Timsina & Connor 2001). Indian Indo-Gangetic Plains contribute approximately 23% of rice and 34% of wheat to countries total production through its rice–wheat cropping system (RWCS). Continuous cultivation of RWCS for decades has led to plateaued productivity levels and associated depletion of natural resources (Ladha et al. 2003; Pathak et al. 2003; Rodell et al. 2009). Results of long-term experiments on RWCS displayed a declining trend of rice yield at 0.02 t ha⁻¹ year⁻¹ or 0.5% year⁻¹ (Yadav et al. 1998; Dawe et al. 2000).

Additionally, rice is a water-guzzling crop having an evapotranspiration requirement of more than 1000 mm (Meena et al. 2015, 2019b; Tripathi et al. 2019) with a very low water productivity. India is withdrawing huge amount of groundwater (Mukherjee et al. 2015) and consumes 25% share of the global use (Margat and van der Gun 2013). The rate of reduction in ground water levels in India is fastest in the world (Aeschbach-Hertig and Gleeson 2012). Continuous practice of RWCS has led to emergence of various other problems such as increased incidence of crop bound weeds like Phalaris minor in wheat (Singh 2007; Kumar et al. 2013; Sharma et al. 2015), delayed sowing of wheat due to delay in harvesting of rice which is causing yield reductions in wheat (Tripathi et al. 2005), declining soil fertility particularly in the form of reduced organic carbon content (Nambiar and Abrol 1989; Ladha et al. 2000), imbalanced use of inorganic chemical fertilizers (Singh et al. 2010; Coventry et al. 2011), and specifically K usage showed a negative balance in Haryana state (Pathak et al. 2003). The combined effect of all above ill effects is leading to decline in factor productivity, raised cost of cultivation, and enhanced environmental pollution (Sunitha 2013; Sinha et al. 2015).

To overcome these problems, there is an urgent need to diversify the RWCS and identify alternate crop combinations which is sustainable and environment friendly in long run. This prompted an investigation into alternate cropping sequence
which could enhance yield with less water use. Therefore, the proposed study focused on replacing the rice crop with maize and sorghum-based cropping sequences to enhance productivity, profitability, and sustainability of the system.

2 Materials and methods

2.1 Experimental site

Field experiments were conducted at the research farm of ICAR — Indian Institute of Wheat and Barley Research, Karnal, Haryana (latitude 29° 43′ N, longitude 76° 58′ E, and altitude 245 m) for four consecutive years commencing from 2016–2017 to 2019–2020.

2.2 Weather condition

This location represents a semiarid climate with long-term average annual precipitation of 600 mm, which is erratic. Most of the precipitation (70–80%) received during the monsoon period, i.e., July to September. The temperature ranged from a minimum of 1–2 °C in December to a maximum of 44–45 °C in May–June. The maximum temperature during the study period was higher in February, March, and April in 2016 and 2017 and June in 2019 as compared to the long-term average. During the rest of the period, it was close to the long-term average or lower, whereas the minimum temperature was higher in March, April, May, and June in 2016, 2017, and 2018 and August, September, October, and November in 2019 as compared to the long-term average. Significant precipitation was recorded in January of all the years while March 2020 recorded an exceptional higher rainfall than the long-term average (Fig. 1).

2.3 Chemical analysis of soil

The soil samples (0–15 cm) were analyzed for pH, EC, organic carbon (Walkley and Black 1934), available N (Jackson 1958), available P (Olsen 1954), and available K (Merwin and Pech 1951) at the start of the experiment and after completion of 4 cropping cycles. The soil of the experimental plot was coarse sandy loam in texture having alkaline pH (8.3), low EC (0.14dSm⁻¹), organic carbon (0.36%), and available nitrogen (115.2 kg ha⁻¹), and medium in available phosphorous (12.0 kg ha⁻¹) and potassium (155.9 kg ha⁻¹) contents.

2.4 Experimental design, treatments, and crop management

Eight crop sequences were studied in a randomized block design with three replications and each crop used in the cropping system is mentioned as under.

| No | Treatments | Crops grown |
|----|------------|-------------|
| 1  | SW         | Sorghum-wheat |
| 2  | SWM        | Sorghum-wheat-mung bean (Vigna radiata) |
| 3  | SMuM       | Sorghum-mustard-mung bean (Vigna radiata) |
| 4  | SPW        | Sorghum-potato-wheat |
| 5  | MPW        | Maize-potato-wheat |
| 6  | MMuM       | Maize-mustard-mung bean (Vigna radiata) |
| 7  | MWM        | Maize-wheat-mung bean (Vigna radiata) |
| 8  | MW         | Maize-wheat |

Varieties, seed rates, and fertilizer doses applied to different crops are given in Table 1. All the crops received phosphorous and potash through DAP (diammonium phosphate) and murate of potash as basal, respectively. 150 kg N ha⁻¹ was applied in sorghum fodder and maize crop with two split applications, i.e., 50% N basal and 50% N in sorghum at 45 DAS (days after sowing), whereas in maize crop, N was applied in three equal split doses, i.e., 1/3 N basal, 1/3 N at 30 DAS, and 1/3 N at 60 DAS. The wheat crop also received N fertilizer in three splits, i.e., 1/3rd of nitrogen was applied at the time of sowing as basal dose, 1/3rd N was applied at the first node stage, i.e., DC 31 (Zadoks et al. 1974), and the remaining 1/3rd N was applied at late jointing (DC37). Mustard and potato received N in two equal splits, i.e., first 50% basal in both cases and second 50% at flowering in mustard and at earthing in potato, respectively. Mung bean cultivation did not receive any fertilizer. For weed control in wheat, two herbicides were sprayed, i.e., sulfosulfuron @ 25 g ha⁻¹ and metsulfuron @ 4 g ha⁻¹, respectively in 400 l of water at 30 DAS. Weeds in maize were controlled by the application of atrazine 1.0 kg ha⁻¹ at 20 DAS. Weeds in crops like potato, mustard, and mung bean were controlled manually with the help of hand hoe. Irrigation in all the crops was applied as per the recommendation of the region. Aphids in mustard were controlled by application of Rogor 30 EC @ 1 l ha⁻¹ in 500 l of water. Sorghum crop was cut at 50% flowering stage and sold in the local market for fodder use.

2.5 Observations

The net plot of each crop was harvested for recording the yield data on a plot basis. The duration taken by each crop from sowing to harvesting was added to calculate the total duration of each crop rotation. Land use efficiency was calculated as the duration of crop sequence divided by 365 days. Production efficiency was calculated as wheat equivalent yield in a cropping sequence divided by the duration of that cropping sequence (Tomar and Tiwari 1990).
2.6 System productivity

System productivity in terms of wheat equivalent yield (WEY) was calculated by multiplying yield with minimum support price-market price of each crop in a cropping sequence and subsequently adding and thereafter divided by the price of one-ton wheat.

\[
WEY = \frac{(\text{Yield of intercrops} \times \text{market price of intercrops})}{\text{Market price of wheat}}.
\]

2.7 Sustainability value index (SVI)

\[
SVI = \frac{(\mu - \delta)}{Y_{\text{max}}},
\]

where \(\mu\) is the mean of a particular treatment in monetary terms, \(\delta\) is the standard deviation of a particular treatment in monetary terms, and \(Y_{\text{max}}\) is the potential maximum monetary returns (by converting potential maximum yield in
monetary terms) over the years. The sustainable value index was calculated as per the procedure described by Singh & others (1990).

2.8 Gross returns and margins

Cost of cultivation was calculated by taking into account the prevailing price of inputs like fertilizer, seed, herbicides, irrigations, tillage operations, transportation charges, management charges, rental value of land, and depreciation cost of implements. Total returns (TR) were calculated by taking minimum support price of maize, mustard, wheat, and mung bean and market price of sorghum (fodder), potato tuber, and wheat straw on pooled yield basis. Net return (NR) was calculated by subtracting cost of cultivation from TR whereas benefit to cost ratio (B:C) was calculated by dividing TR with cost of cultivation.

2.9 Statistical analysis

The data recorded for different parameters were analyzed with the help of analysis of variance (ANOVA) techniques for randomized block design using SAS (Statistical Analysis Software) version 10.3. Yearly as well as combined over the years, analysis was performed for all the parameters under study. The least significant difference (LSD) test was used to compare mean differences between treatments at $P = 0.05$.

3 Results

3.1 Analysis of variance

Highly significant differences were observed for WEY, TR, NR, BC ratio, and PE at a 5% level of significance. The main effects of year and treatments were found to be significant ($P < 0.001$) (Table 2). One-way interaction involving year × treatments was also found significant ($P < 0.001$). Comparing the years, 2018 was significantly superior for WEY (14.4 t ha$^{-1}$ year$^{-1}$), TR (3222 $\$/ha$), NR (1168 $\$/ha$), BC ratio (1.59), and PE (51.3 kg ha$^{-1}$ day$^{-1}$) compared to that other three years. The years 2016 and 2017 were statistically at par ($P > 0.05$) while, 2020 recorded significantly ($P < 0.001$) lowest values concerning all the studied parameters among the years (Fig. 2).

3.2 Yield of different crops

The study revealed that the yield produced by different component crops varied among the different cropping sequences (Table 3). Maize yields were maximum under MWM (7.6 t ha$^{-1}$ year$^{-1}$) sequence while wheat recorded maximum yield under SW (6.1 t ha$^{-1}$ year$^{-1}$) sequence. The lowest maize yield (6.6 t ha$^{-1}$ year$^{-1}$) was achieved when the potato was grown in between maize and wheat. Late sown wheat variety sown after potato produced lower grain yield (3.2 and 3.7 t ha$^{-1}$ year$^{-1}$) as compared to timely sown variety taken after sorghum (6.1 and 5.7 t ha$^{-1}$ year$^{-1}$) and maize (5.4 and 5.7 t ha$^{-1}$ year$^{-1}$) based crop sequences. The average mustard (1.9 t ha$^{-1}$ year$^{-1}$) and potato (20.3 t ha$^{-1}$ year$^{-1}$) yields were numerically higher when maize was as a preceding crop compared to sorghum. In contrast, mung bean (1.4 t ha$^{-1}$ year$^{-1}$) yield was higher when sorghum was the preceding crop compared to maize (1.2 t ha$^{-1}$ year$^{-1}$).

Table 1 Varieties, seed rates, and fertilizer doses applied to different crops

| Crops     | Varieties | Seed rate (kg/ha) | N  | P$_2$O$_5$ | K$_2$O |
|-----------|-----------|------------------|----|------------|--------|
| Sorghum   | Manak     | 40               | 150| 60         | 40     |
| Maize     | X-92      | 20               | 150| 60         | 40     |
| Wheat (TS)| HD 3086   | 100              | 150| 60         | 40     |
| Wheat (LS)| DBW 71    | 125              | 120| 60         | 40     |
| Mustard   | Pusa bold | 3                | 90 | 60         | 40     |
| Potato    | KufriPokhraj | 2500           | 90 | 80         | 100    |
| Mung bean | SML-668   | 25               |    |            |        |

*Applied through urea, diammonium phosphate, and murate of potash

Table 2 ANOVA on productivity, profitability, and soil health parameters

| Source  | Productivity and profitability | pH | Soil health parameters |
|---------|--------------------------------|----|-----------------------|
|         | WFY | PE | TR | NR | B:C | EC | OC | N | P | K |
| Year (Y)| 3   | $<0.001$ | $<0.001$ | $<0.001$ | $<0.001$ | - | - | - | - | - |
| Treatment (T) | 7 | $<0.001$ | $<0.001$ | $<0.001$ | $<0.001$ | 0.17 | 0.535 | $<0.001$ | 0.021 | $<0.001$ |
| Y*T     | 21  | $<0.001$ | $<0.001$ | $<0.001$ | $<0.001$ | $<0.001$ | - | - | - | - |

WEY, wheat equivalent yield (t ha$^{-1}$ year$^{-1}$); PE, production efficiency (%); TR, total returns ($$/ha$$); NR, net returns ($$/ha$$); BC ratio, benefit to cost ratio; EC, electrical conductivity (dS m$^{-1}$); OC, organic carbon (%); N, nitrogen (kg ha$^{-1}$); P, phosphorus (kg ha$^{-1}$); K, potassium (kg ha$^{-1}$)
System productivity measured as wheat equivalent yield (WEY) was significantly \((P < 0.001)\) higher under MPW sequence \((16.49 \text{ t ha}^{-1} \text{ year}^{-1})\) and MWM \((16.17 \text{ t ha}^{-1} \text{ year}^{-1})\) rotations than others (Fig. 3). This was followed by the MMuM sequence \((14.42 \text{ t ha}^{-1} \text{ year}^{-1})\) at second rank, SPW \((13.53 \text{ t ha}^{-1} \text{ year}^{-1})\), and SWM \((13.39 \text{ t ha}^{-1} \text{ year}^{-1})\) which were at third and fourth position, respectively along with MW \((13.73 \text{ t ha}^{-1} \text{ year}^{-1})\) on the Tukey ranking. The crop sequences SMuM \((11.59 \text{ t ha}^{-1} \text{ year}^{-1})\) and SW \((10.85 \text{ t ha}^{-1} \text{ year}^{-1})\) were the lowest ranking crop.

### Table 3

| Crop Sequences | Maize | Sorghum (F) | Wheat | Mustard | Potato | Mung bean |
|----------------|-------|-------------|-------|---------|--------|-----------|
| SW             | 48.82 | 6.09        | 0.00  | 0.00    | 0.00   | 0.00      |
| SWM            | 41.31 | 5.69        | 0.00  | 0.00    | 1.18   | 0.00      |
| SMuM           | 50.29 | 0.00        | 1.84  | 0.00    | 1.59   | 0.00      |
| SPW            | 49.52 | 3.24        | 0.00  | 19.97   | 0.00   | 0.00      |
| MPW            | 6.69  | 3.66        | 0.00  | 20.26   | 0.00   | 0.00      |
| MMuM           | 7.00  | 0.00        | 1.91  | 0.00    | 1.55   | 0.00      |
| MWM            | 7.66  | 5.36        | 0.00  | 0.00    | 0.93   | 0.00      |
| MW             | 7.55  | 5.67        | 0.00  | 0.00    | 0.00   | 0.00      |

\(F,\) fodder

### 3.3 System productivity

System productivity measured as wheat equivalent yield (WEY) was significantly \((P < 0.001)\) higher under MPW sequence \((16.49 \text{ t ha}^{-1} \text{ year}^{-1})\) and MWM \((16.17 \text{ t ha}^{-1} \text{ year}^{-1})\) rotations than others (Fig. 3). This was followed by the MMuM sequence \((14.42 \text{ t ha}^{-1} \text{ year}^{-1})\) at second rank, SPW \((13.53 \text{ t ha}^{-1} \text{ year}^{-1})\), and SWM \((13.39 \text{ t ha}^{-1} \text{ year}^{-1})\) which were at third and fourth position, respectively along with MW \((13.73 \text{ t ha}^{-1} \text{ year}^{-1})\) on the Tukey ranking. The crop sequences SMuM \((11.59 \text{ t ha}^{-1} \text{ year}^{-1})\) and SW \((10.85 \text{ t ha}^{-1} \text{ year}^{-1})\) were the lowest ranking crop.
sequences for WYE. Maize-based crop sequences recorded higher WYE (13.73–16.49 t ha\(^{-1}\) year\(^{-1}\)) than sorghum-based crop sequences (10.85–13.53 t ha\(^{-1}\) year\(^{-1}\)). This clearly showed that maize-based cropping system was a more efficient production system.

### 3.4 Land use efficiency (LUE)

Land use efficiency determines the percent of time land was cultivated with crops so that barren percent area can be reduced. Low LUE refers to that, crop can be taken in a short period whereas high LUE indicates coverage of land most of the time and thereby reducing the erosion losses. In this study, MWM showed maximum LUE (87.67%) followed by MMuM (83.56%) whereas the lowest was recorded in SW (63.56%). As sorghum was harvested as fodder at 50% flowering, sorghum-based crop sequences showed lower LUE (63.56–82.74%) as compared to maize-based rotations (68.41–87.67%).

### 3.5 Production efficiency (PE)

MPW (56.87 kg ha\(^{-1}\) day\(^{-1}\)) and MW (54.90 kg ha\(^{-1}\) day\(^{-1}\)) exhibited similar PE values but were significantly

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**Fig. 3** Variation in wheat equivalent yield, land use efficiency, production efficiency, and sustainable value index under different cropping systems. Note: Alphabet(s) following the mean values is based on Tukey’s test of significance. For each treatment, mean values followed by same letters are not significantly different at 0.001 probability level.

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(P = <0.001) higher than other crop sequences. MWM also showed significantly lower PE than earlier mentioned rotations but was higher (P = <0.001) than all other crop sequences except SPW. The lowest PE was obtained by SMuM (40.39 kg ha$^{-1}$ day$^{-1}$) crop sequence, which was significantly lower (P = <0.001) than all other crop sequences. Maize-based crop sequences exhibited higher PE (47.3–56.9 kg ha$^{-1}$ day$^{-1}$) than sorghum-based crop sequences (40.4–49.8 kg ha$^{-1}$ day$^{-1}$) which clearly indicated an efficient production system with maize (Fig. 3).

3.6 Sustainable value index (SVI)

The sustainable value index determines returns available with minimum fluctuations over the period. Crop sequences SMG (0.96) and MWM (0.95) showed maximum SVI as compared to other crop rotations. In contrast, the lowest SVI was obtained with MW rotations (0.89). All the sorghum and maize-based crop sequences produced better SVI indicating that these cropping sequences can be good alternative options in place of rice for the farmers.

3.7 Gross returns and margins

MPW (3671.7 $ ha$^{-1}$) and MWM (3598.9 $ ha$^{-1}$) recorded significantly (P = <0.001) higher total returns, compared to all other crop rotations, whereas lowest total returns were earned in SW (2415 $ ha$^{-1}$) and SMuG (2580 $ ha$^{-1}$) crop sequences, which were significantly (P = <0.001) lower than all other sequences. The maximum cost of cultivation (SPW = 2590 $ ha$^{-1}$ and MPW = 2582 $ ha$^{-1}$) was incurred in crop sequences where potato crop was a component and minimum in SW (1684 $ ha$^{-1}$) and MW (1676 $ ha$^{-1}$) crop sequences, which showed only 200% crop intensity. MWM recorded maximum net return (1577.1 $ ha$^{-1}$), which was significantly (P = <0.001) higher than all other crop rotations and 115.59% higher than SW crop sequence. The next best-earning crop rotations were MW (1379.4 $ ha$^{-1}$) and MMuM (1287.7 $ ha$^{-1}$), which were statistically at par. On the other hand, significantly (P = <0.001) lowest net return of 422.6 $ ha$^{-1}$ was obtained in SPW rotation. Maximum benefit:cost ratio was obtained for MW (1.82) and MWM (1.78), which was significantly (P = <0.001) higher than other crop sequences. In contrast, the lowest B:C ratio was obtained for SPW (1.16) rotation, which was significantly (P = <0.001) lower than all other crop sequences in this study. In general, maize-based crop sequences have shown higher total return, net return, and B:C ratio than sorghum-based crop sequences owing to their higher productivity (Fig. 3).

3.8 Soil fertility

Maximum pH was recorded in MPW (8.42) rotation alone after four cycles of crop sequence, which was higher while most of the rotations reduced the pH compared to the initial level. There was no significant difference in EC level and available P among the cropping sequences. Organic carbon and available N were significantly (P = <0.001) higher in the crop sequences where mung bean was included as one of the component crops either in sorghum or in maize-based crop sequences. After four crop cycles, the MMuM crop sequence recorded 28.65% and 34.91% higher organic carbon and available N as compared to the initial soil level, respectively. MMuM and SWM recorded significantly (P = <0.001) higher available K as compared to other crop sequences. The former one recorded almost 25.16% higher available K in soil than the initial level (Fig. 4).

4 Discussion

System productivity plays an important role in the comparison of various cropping sequences. MPW and MWM cropping systems recorded 51.99% and 48.98% higher WEY, respectively as compared to the lowest SW treatment. Generally, when cropping intensity increased from 200 to 300% by taking three crops in a year, this increases WEY. Earlier, in a study, Chauhan et al. (2001) reported that the inclusion of potato as one of the component crops in between the rice and late wheat enhances the system productivity significantly. In a similar kind of study, Bhargavi and Behera (2019) observed that diversified cropping systems like maize-pea-okra, maize-mustard-mung bean, and cotton-wheat under marginal farmer’s situations produced higher system productivity. Diversified cropping systems enhanced crop productivity across rotation as compared to the less diversified systems. A meta-analysis of 45 studies in China (Zhao et al. 2020) found that rotations increase crop productivity up to 20% as compared to continuous monoculture. Growing of pulse crop cowpea after wheat increased the crop productivity of rice up to 8.35% (Tripathi et al. 2019). In a study of cereal and legume intercropping by using $^{15}$N isotopes, authors (Jensen et al. 2020) reported that cereal benefits more when grown in association with legumes and N requirement can be reduced by 26% on a global scale basis.

Increasing cropping intensity from 200 to 300% also enhances land use efficiency. MWM and MMuM are having 300% cropping intensity and showed up to 87.67% higher LUE, which was the maximum under the study. Even 200% cropping intensity rotation like sorghum-berseem (Trifolium alexandrinum) showed 78.35% LUE.
due to the long duration of berseem owing to its repeated cutting for fodder (Singh et al. 2008). Four crops, i.e., rice-vegetable pea-wheat-mung bean grown in a year showed more than 96% LUE (Tripathi and Singh 2007). Therefore, this whole system depends upon the number of crops grown in a calendar year and their duration.

Production efficiency, i.e., yield per unit area and per unit time of MPW crop sequence was maximum. The inclusion of potato in the cropping system enhances the PE (Singh et al. 2011). Differences in PE among rotations were reported by Tripathi (2008) where authors elaborated that it is not governed by the number of crops grown in a calendar year but an efficient production system for the economic yield. The sustainability of the cropping system can be determined by SVI and in this study, higher SVI was obtained by SMuM and MWM cropping sequences. Intensification of the rice–wheat system by inclusion of mung bean leading to enhanced sustainability and PE was also reported previously (Chauhan et al. 2001; Tripathi et al. 2004). Higher SVI indicated that new proposed cropping systems are more stable and enriching the soil fertility with inclusion of mung bean.

Maize-based crop sequences recorded a higher total return, net return, and B:C ratio than sorghum-based crop sequences. This showed that maize is more productive and profitable than sorghum, which was taken as a fodder crop. In a study of maize-based crop sequences, it was observed by various authors (Gangwar and Singh 2011; Meena et al. 2015; Bhargavi and Behera 2019) that maize-based systems resulted in higher net return as compared to rice–wheat system. Another way to enhance the economic return is to intensify the rice–wheat system by the inclusion of pulses so that 300% cropping intensity could be achieved (Tripathi 2008; Jat et al. 2012; Tripathi et al. 2019). In another study, the inclusion of mung bean in the MWM crop sequence enhanced the net return by 14.33% as compared to MW rotation while Choudhary et al. (2018) also observed that the inclusion of mung bean in cereal systems contributed to a 15% increase in profitability. Inclusion of potato in the crop rotation increases the cost of cultivation due to its tuber cost.
and thereby net return and B:C ratio is lower as compared to other maize-based crop sequences. This finding is in agreement with earlier observation (Chauhan et al. 2001).

Comparison of water requirement of different alternative cropping systems revealed that the proposed cropping system will require far less water and will save 170- to 600-mm irrigation water than RWCS (Table 4). MMuM cropping system saves irrigation water by about 47.67% when compared to RWCS. The proposed new cropping system having three crops in total requires 860 mm of irrigation water, viz. maize = 480 mm (Brar et al. 1989); mustard = 200 mm (Bhola et al. 1991); and mung bean = 180 mm (Prasad et al. 1990), whereas RWCS requires 1270 mm of irrigation water, viz. rice = 1000 mm (Meena et al. 2015; Tripathi et al. 2019) and wheat = 270 mm (Meena et al. 2019b). Therefore, the proposed new cropping system is highly water use efficient which could contribute significantly in reverting the present scenario of fast depleting ground water table in North West India. Noteworthy to mention that even inclusion of mung bean requires far less water than RWCS and exhibits 300% cropping intensity, higher WEY and returns besides improving the soil fertility particularly organic carbon content of the soil.

MMuM crop sequence exhibited 28.65% and 34.91% higher organic carbon and available N as compared to pre-experiment levels which were 0.36% OC and 115.22 kg ha\(^{-1}\) available N. MMuM, MWM, SMuM, and SWM crop rotations where mung bean was included had shown tremendous increase in organic carbon and available N after 4-year study. This revealed that continuous growing of pulses and incorporating their residue enriches the soil fertility as well as brings pH towards neutrality. An increase in soil health in the form of higher organic carbon by the cultivation of a pulse crop was previously studied by different researchers (Beri et al. 1989; Kharub et al. 2003; Singh and Sidhu 2014; Tripathi et al. 2019; Singh et al. 2020). Growing mung bean, cowpea, and vegetable pea increased the organic carbon content by 42.89%, 16.38%, and 4.57%, respectively in a span of 8 years (Tripathi et al. 2019). In the post-rainy season, there is a demand for green fodder, which can be fulfilled with sorghum-based crop sequences like rice-sorghum-mung bean. This will provide a nutritious diet to the family while maintaining soil fertility through the inclusion of legumes (Jat et al. 2012).

## 5 Conclusions

To bring out a sustainable and profitable solution for the challenges posed by the rice–wheat cropping system leading to air pollution and decline in soil health, diversification and/or intensification of the system was tested for 4 years. The results revealed that there is sufficient scope to replace the rice–wheat cropping system with other cropping systems without any decline in economic yield rather it improved substantially. System productivity in terms of wheat equivalent yield was maximum for the maize-potato-wheat (16.49 t ha\(^{-1}\) year\(^{-1}\)) and maize-wheat-mung bean (16.17 t ha\(^{-1}\) year\(^{-1}\)) rotations. Maize-wheat-mung bean (87.67%) showed maximum land use efficiency; maize-potato-wheat (56.87 kg ha\(^{-1}\) day\(^{-1}\)) produced maximum production efficiency; sorghum-mustard mung bean (0.96) and maize-wheat mung bean (0.95) recorded maximum sustainable value index; maize-wheat mung bean recorded maximum net return (1577.1 $ ha\(^{-1}\)), which was 115.59% higher than sorghum-wheat. Comparison between maize and sorghum-based crop sequences showed that maize-based crop sequences recorded higher total return, cost of

### Table 4 Irrigation water requirement (WR) for different cropping systems

| Treatments | Crops grown | Total WR, mm | References |
|------------|-------------|--------------|------------|
| SW         | Sorghum (400 mm)-wheat (270 mm) | 670          | Rao and Rana 1987, Meena et al. 2019b |
| SWM        | Sorghum (400 mm)-wheat (270 mm)-mung bean (180 mm) | 850          | Rao and Rana 1987, Prasad et al. 1990; Meena et al. 2019b |
| SMuM       | Sorghum (400 mm)-mustard (200 mm)-mung bean (180 mm) | 780          | Rao and Rana 1987; Prasad et al. 1990; Bhola et al. 1991 |
| SPW        | Sorghum (400 mm)-potato (350 mm)-wheat (270 mm) | 1020         | Rao and Rana 1987; Sood and Sharma 1993; Meena et al. 2019b |
| MPW        | Maize (480 mm)-potato (350 mm)-wheat (270 mm) | 1100         | Brar et al. 1989; Sood and Sharma 1993; Meena et al. 2019a |
| MMuM       | Maize (480 mm)-mustard (200 mm)-mung bean (180 mm) | 860          | Brar et al. 1989; Prasad et al. 1990; Bhola et al. 1991 |
| MWM        | Maize (480 mm)-wheat (270 mm)-mung bean (180 mm) | 930          | Brar et al. 1989; Prasad et al. 1990; Meena et al. 2019a |
| MW         | Maize (480 mm)-wheat (270 mm) | 750          | Brar et al. 1989; Meena et al. 2019a |
| RW         | Rice (1000 mm)-wheat (270 mm) | 1270         | Tripathi et al. 2019; Meena et al. 2019a |
Maize-mustard mung bean cropping system increased the organic carbon content by 28.65% and available N by 34.91% as compared to the initial soil level. These alternative crop sequences will save water from 170 to 600 mm as compared to rice–wheat system. Inclusion of mung bean not only enhances the organic carbon content but also reduces the import burden of the country by saving forex. Therefore, maize-based crop sequences can fit well in replacing the rice crop and simultaneously increasing productivity and profitability, and enhancing efficiency in a sustainable manner.

Author contribution S C Tripathi — conduction of experiment, data recording, drafting, and editing of manuscript. Karnam Venkatesh — data analysis and editing of manuscript. Ral Pal Meena — review and literature, editing of manuscript.

Funding The research work was funded by Indian Council of Agricultural Research at Indian Institute of Wheat and Barley Research, Karnal, Haryana, India.

Availability of data and material All the data will be available if request is made.

Code availability Project No. CRSCIIWBSRL.201500800189.

Declarations

Ethics approval All authors approve ethical responsibilities related with this manuscript.

Consent to participate All authors give their consent to participate.

Consent for publication All authors give their consent for publication in Theoretical and Applied Climatology.

Conflict of interest The authors declare no competing interests.

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