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Impact of Land Configuration and Strip-Intercropping on Runoff, Soil Loss and Crop Yields under Rainfed Conditions in the *Shivalik* Foothills of North-West, India

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Abstract: Maintaining sustainable crop production on undulating, sloppy, and erodible soils in *Shivalik* foothills of North-west India is a challenging task. Intercropping is accepted as a highly sustainable system to reduce soil erosion and ensure sustainable production by making efficient use of resources. Field experiments were conducted in the rainy season (July to September) during 2015, 2016, and 2017 to evaluate the effect of land slopes and maize and cowpea strip-intercropping on productivity and resource conservation at the Regional Research Station, Ballowal Saunkhri located in the *Shivalik* foothills. During three years of experimentation, a total of 23–26 runoff events were observed in the maize crop grown in the rainy season. The results from this 3-year field study indicate that maize grain yield was significantly higher on a 1% slope and cowpea on a 2% slope. This accounted for significantly higher net returns (US$ 428 ha^{-1}) with a benefit-cost (BC) ratio of 2.0 on a 1% slope. Runoff, soil, and nutrient losses were higher on a 3% slope as compared to 1% and 2% slopes. N, P, and K loss on a 3% slope were 3.80, 1.82, and 4.10 kg ha^{-1} higher, respectively than a 1% slope. The adoption of a strip-intercropping system with a 4.8 m maize strip width and 1.2 m cowpea strip width resulted in significantly higher maize equivalent yield than sole maize and other strip-intercropping systems. This system showed the highest land equivalent ratio value (1.24) indicating a 24% yield advantage over sole cropping systems of maize and cowpea, and fetched the highest net returns (US$ 530 ha^{-1}) with a benefit-cost ratio (BC ratio) of 2.09. This system also reduced runoff and soil loss by 10.9% and 8.3%, respectively than sole maize crop. On all the land slopes, maize and cowpea strip-intercropping systems showed a significant reduction in N, P, K, and organic carbon loss as compared to sole maize. Thus, on sloping land, the maize and cowpea strip-intercropping system decreases surface runoff, soil, and nutrient loss, and increases yield and income of the farmers as compared to a sole maize crop.

Keywords: maize equivalent yield; nutrient loss; runoff; soil loss; slope; strip-intercropping; water use efficiency

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1. Introduction

Water and wind erosion are the main soil degradation processes in drylands of the world [1]. Soil erosion not only affects the soil's physical properties but transports huge quantities of nutrients from agricultural land thereby deteriorating the soil health [2]. Soil erosion has detrimental impacts on global agricultural production as more than half (52%) of the world's arable soils have been categorized as degraded or severely degraded [3,4]. Soil erosion rate from agricultural land is about 10–100 times greater than rates of soil production, erosion under natural vegetation, and long-term geological erosion [5]. Over the last two decades, estimates for agricultural land degradation have been highly variable with figures varying from as low as 15% to as high as 80% [6–11]. Later assessments have revealed that 25%, 44%, and 10% of the present agricultural land are highly degraded, slightly to moderately degraded, and recovering from degradation, respectively [7,8,12]. The global average annual value of soil erosion is about 10.2 Mg ha^{-1}, of which 60% is anthropogenic. Soil erosion results in an $8 billion loss to global GDP annually which has reduced the crop yields by 33.7 Tg (Teragrams ≈ million tonnes), and increased water abstraction by 48 billion m^3 [13]. In India, water erosion has affected about 145 million hectares of the total geographical area (328.81 million hectares). In the north-western part of India, the sub-mountainous area in the *Shivalik* foothills popularly known as the *Kandi* region is deemed as one of the most fragile ecosystems of the country. In this region, a large portion of the rainfall goes as runoff from the cultivated fields along with fertile topsoil [14,15]. The average annual erosion rate in this region is 16 Mg ha^{-1} and in some watersheds, it is more than 80 Mg ha^{-1} [16,17], which is much higher than the soil tolerance limit of 10–11.2 Mg ha^{-1} [18]. Due to the severe erosion problems, huge quantities of nutrients are lost from fertile agricultural land, rendering them barren over a period of time [18–21]. Therefore, there is a need to identify a suitable cropping system that can provide adequate soil cover to reduce the rate of soil loss to a tolerable limit and ensure sustainable crop production while maintaining the proper soil health. Maize-wheat is the principal cropping system of the *Shivalik* foot-hills. Maize, being the erosion permitting crop, augments the problem of soil erosion which is further aggravated by the high-intensity rainstorms. Hence, maize must be grown with erosion-resistant crops so as to minimize soil erosion to an acceptable level. Leguminous crops are considered to be the best soil conservators, and legumes, when grown as intercrops, impart sustainability in the cropping system [21]. Among the various factors affecting the runoff and soil erosion process, the vegetation cover in terms of structure and density plays an important role in runoff generation and hence, the soil erosion process. The vegetation cover not only reduces the amount of rainfall reaching the ground surface but also reduces the impact of raindrops on the soil surface [22]. Due to less impact velocity, the splash erosion is reduced to a larger extent. The amount of soil detached is reduced considerably due to the presence of surface/crop cover and hence the gross soil erosion is reduced as well [23]. A number of studies have been conducted wherein it has been observed that adding vegetation cover by mulching or intercropping has reduced runoff and soil loss [24–27].

Intercropping, the practice of growing two or more crops simultaneously on the same field is an age-old cropping system that aims to utilize the growth resources more efficiently than sole cropping [28]. Intercropping is identified as a cropping system that not only controls the soil loss from the agricultural fields but also increases the crop yields and enhances the soil moisture in the crop root zone [29,30]. The main advantage of intercropping is the more efficient utilization of the available resources and the increased productivity compared with each sole crop of the mixture [31,32]. Intercropping results in better pest control and reduced soil erosion [28]. Sharaiha and Ziadat [33] reported that the intercropping of vetch and barley resulted in significantly higher yields due to a reduction in runoff and soil losses. Sharma and Arora [21] conducted a study in the *Shivalik* foothills to evaluate the different intercropping systems and concluded that the intercropping not only increased yields but also conserved soil moisture. Ghosh et al. [34] reported that intercropping results in higher grain yields, net returns, and water use efficiency. Wang et al. [35] stated that hedgerow intercropping reduced the runoff, soil loss, and nutrient loss significantly as compared to sole maize crop. Sharma et al. [36] reported intercropping conserved the soil moisture in the *kharif* season, which resulted in higher crop yields during the *rabi* season, and it also reduced the runoff and soil loss by 26% and 43%, respectively.

In the rainfed tracts of Northwest India, maize is the dominant crop in the rainy (kharif) season. However, maize is an erosion permitting crop and must be grown in combinations with erosion-resistant crops preferably legumes, which due to its thick canopy cover reduces the soil and nutrient losses [37]. Few researchers have reported that crop covers proved effective in controlling runoff and soil loss in the region. Yet, limited information is available on runoff, soil, and nutrient losses under different vegetative covers in the *Shivalik* foothills region of Punjab, India. We hypothesized that the strip intercropping would result in reduced soil and nutrient loss and increase crop productivity under the different land configurations prevalent in the *Shivalik* foothills of India. Keeping this in view, the present study was conducted to evaluate the different combinations of maize and cowpea strip widths on different land slopes and their impact on soil and nutrient losses, productivity, and profitability. The objectives of the present study were (i) to determine the changes in maize and cowpea productivity from 2015 to 2017; (ii) to determine the runoff and soil loss on different land slopes and maize and cowpea strip widths, and; (iii) to identify the best combination of land slope and maize and cowpea strip width in terms of profitability and soil conservation.

2. Materials and Methods

2.1. Experimental Site

Field experiments were conducted in the rainy season (July to September) during 2015, 2016, and 2017 at the Research Farm of Punjab Agricultural University Regional Research Station, Ballowal Saunkhri, Shaheed Bhagat Singh Nagar, Punjab, India. The experimental site is geographically located between 31°6′5″ N latitude, 76°23′26″ E longitude, and at an altitude of 346 m in the *Shivalik* foothills. The climate of the region is sub-humid with hot and dry summer and extremely cold winter. The average annual rainfall of the region is 1060 mm of which 80% is received in a span of three months from mid-June to mid-September. In the past 35 years, annual rainfall has declined from over 1200 mm to 1060 mm. However, the extreme rainfall events with high intensity have increased with a decrease in the number of rainy days in the *kharif* season [38]. During the crop period 2015, 2016, and 2017, the rainfall received were 414 mm, 508.7 mm, and 726.9 mm, respectively with 6, 8, and 12 runoff events. The mean monthly minimum and maximum temperature ranged from 5.9 to 25.2 and 18.8 to 38.6 °C during the year with their respective plateau in December and May, respectively (Figure 1).

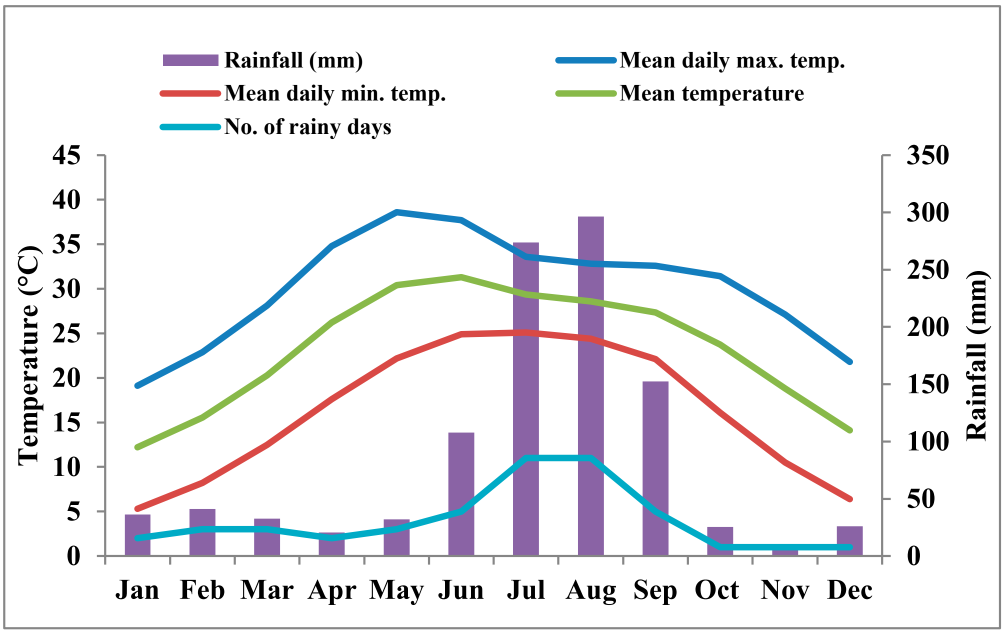

Figure 1. Ombroclimatic diagram of the study site (Mean data from 1984 to 2017).

The soil of the experimental field was loamy in texture, low in organic carbon (0.40%), available N (224 kg ha^{-1}), and medium in P (13 kg ha^{-1}) and K (192 kg ha^{-1}). The bulk density of soil was 1.54 Mg m^{-3} with pH 8.12 and electrical conductivity 0.25 dS m^{-1}. The soil moisture retention at field capacity (0.3 bars) was 19.4% and at permanent wilting point (15 bars) was 7.2% on a weight basis in a 0–180 cm soil profile. Soil pH was determined by the method of Jackson [39] in a 1:2.5 soil: water suspension, organic carbon by the method of Walkley and Black [40], available nitrogen by the alkaline-$KMnO_4$ method [41], available phosphorus by the Olsen method [42], and exchangeable potassium by the NH_4OAc method [39].

2.2. Experimental Details and Crop Management Practices

The experiment on strip-intercropping of maize and cowpea with different land slopes and variable strip width laid out in a randomized block design with three replications was conducted under rainfed conditions during all the years of experimentation. The treatments consisted of three land slopes, viz. (i) 1% slope (S1), (ii) 2% slope (S2), and (iii) 3% slope (S3); and five strip widths of maize and cowpea viz. (i) sole maize 6 m wide (W1), (ii) maize strip 4.8 m and cowpea strip 1.2 m wide (W2), (iii) maize strip 3 m and cowpea strip 3 m wide (W3), (iv) maize strip 1.2 m and cowpea strip 4.8 m wide (W4), and (v) sole cowpea 6 m (W5). The plot size was 12 m × 6 m for W1 and W5 treatments, 12 m × 10.8 m for W2 treatment, 12 m × 9 m for W3 treatment, and 12 m × 7.2 m for W4 treatment. The maize variety PMH-2 was sown at a spacing of 60 cm × 20 cm and cowpea dual-purpose variety CL 367 was sown at 30 cm × 10 cm spacing using 20 kg and 30 kg seed per hectare, respectively. Both the crops were sown across the slope. The recommended dose of N, P, and K for maize was 80, 40, and 30 kg ha^{-1}, respectively, and in cowpea N and P were applied @ 18.75 and 55 kg ha^{-1}, respectively. In cowpea, a full dose of N and P was applied at the time of sowing while in maize, half N and a full dose of P and K were applied as basal, and the remaining half of N was applied at knee height stage about one month after sowing. Nitrogen, phosphate, and potassium were applied through urea, di-ammonium phosphate, and muriate of potash, respectively. Maize and cowpea were sown simultaneously in the 1st week of July. Weeds were managed in the sole and intercropping system with pre-emergence application of herbicide pendimethalin @ 1.5 kg a.i. ha^{-1} followed by one hoeing in maize 25–30 DAS. No insect pest or disease attack was observed in either of the crops.

2.3. Measurement of Leaf Area and Yield

The leaf area of maize and cowpea was measured indirectly at 30 DAS with Sunscan Ceptometer, Delta-T Devices, UK. In the maize and cowpea strip cropping system, the leaf area index (LAI) of both maize and cowpea were added for comparison with sole crops and strip-cropping systems. Maize crop was harvested in the 1st week of October 2015, 2016, and 2017. The maize crop rows from the inner and border strips were harvested separately to record the grain and straw yield. In cowpea, pods were picked from time to time as they matured in 2–3 pickings and harvested in the 2nd week of October to record the fodder yield.

2.4. Measurement of Runoff, Soil Loss, Nutrient Loss, and Water Conservation Efficiency

The total surface runoff and sediments generated from each plot were measured by collecting the runoff in the collection tank (capacity 200 L) installed at the downstream end of each plot. Two drums were arranged in such a way that if the first drum is full; the excess runoff is collected in the second drum. The runoff volumes were measured immediately after the rainfall event. The plots were separated by well-constructed bunds. To measure the soil loss, the runoff water collected in the collection tanks was thoroughly stirred. The runoff samples were then collected from each tank in triplicates in the sediment sampling bottles of capacity 1.0 L. Each sample was carefully transferred to a separate beaker, evaporated in an oven at 40 °C till constant weight to determine the average soil loss per sample. The soil loss per plot was calculated by multiplying the average soil loss per sample and the total volume of runoff generated from the plot. Soil loss was calculated as per the equations given below:

$$Soil\ loss\ (kg\ ha^{-1}) = \frac{Sediment\ weight\ (g\ litre^{-1}) \times Run\ off\ \left(litres\ ha^{-1}\right)}{10^3} \quad (1)$$

A separate runoff sample was also collected from each tank for nutrient analysis. The total nitrogen content of the dry soil was determined using the Kjeldahl digestion and distillation procedure [43]. Available phosphorus was determined using Olsen's method [42] and exchangeable potassium was determined by the flame photometry procedure [39].

The nutrient loss was calculated as per the equations given below:

$$Nutrient\ loss\ (kg\ ha^{-1}) = \frac{Nutrient\ content(mg\ kg^{-1}) \times Soil\ loss\ \left(kgha^{-1}\right)}{10^6} \quad (2)$$

The rainfall conserved and the conservation efficiency of different crops were assessed based on the rainfall of each storm and runoff produced. The crop water productivity was estimated from the total water conserved under the respective crop and the soybean equivalent yield of each crop cover.

The water conservation efficiency (WCE) [44,45] was determined using the following formula:

$$WCE\ (\%) = \frac{Total\ rainfall\ (mm) - Runoff\ (mm)}{Rainfall\ (mm)} \times 100 \quad (3)$$

Water use efficiency (WUE) of treatments was determined by using the formula:

$$WUE\ \left(kgha^{-1}mm^{-1}\right) = \frac{Crop\ yield\ \left(kgha^{-1}\right)}{Crop\ evapotranspiration(mm)} \quad (4)$$

2.5. Intercropping Indices

The advantage of intercropping as compared with sole cropping was evaluated using the maize equivalent yield (MEY) and land equivalent ratio (LER) equation:

MEY was calculated as per the formula given below:

$$MEY\ \left(kgha^{-1}\right) = \frac{Yield\ of\ cowpea\ \left(kgha^{-1}\right)\ x\ Price\ of\ cowpea\ \left(Rskg^{-1}\right)}{Price\ of\ maize\ \left(Rskg^{-1}\right)} + Yield\ of\ maize\ \left(kgha^{-1}\right) \quad (5)$$

LER was calculated as suggested by Willey and Rao [46] by the following formula:

$$LER = \frac{Yield\ of\ intercropped\ maize\ \left(kgha^{-1}\right)}{Yield\ of\ sole\ maize\ \left(kgha^{-1}\right)} + \frac{Yield\ of\ intercropped\ cowpea\ \left(kgha^{-1}\right)}{Yield\ of\ sole\ cowpea\ \left(kgha^{-1}\right)} \quad (6)$$

2.6. Economic Analysis

The cost of cultivation under different treatments was estimated on the basis of market prices of different inputs and outputs in the study area. The input costs include costs of seed, pesticide, fertilizers, hiring charges of human labor, field preparation, fertilizer application, plant protection, harvesting, and threshing. Gross returns were calculated on the basis of market price provided by the market committee, Balachaur, Punjab, India. Net income was calculated as the difference between gross income and total cost. The benefit-cost (B:C) ratio was calculated as gross return divided by the cost of cultivation.

2.7. Statistical Analysis

Analysis of variance (ANOVA) technique in factorial randomized block design was carried to analyze the data statistically using SAS software, version 9.4 [SAS Institute Inc., Cary, NC, USA]. The differences between the treatments were tested by the least significant difference (LSD) at a $p < 0.05$ level of significance.

3. Results

3.1. Productivity

3.1.1. Maize

Maize grain yield obtained on 1% slope was significantly higher than on 2% slope and 3% slope (Figure 2). The yield of maize declined with the increase in slope except in 2015 wherein the yield on the 2% slope was slightly less than the 3% slope. On a mean basis, the grain yield of maize on the 1% slope was 12% and 18% higher than on the 2% slope and 3% slope, respectively. Maize grain yield responded significantly to strip width. Sole maize yield varied from 2137 kg ha^{-1} in 2015 to 3645 kg ha^{-1} in 2017. The yield from a strip-intercropping combination of a 4.8 m maize strip width and 1.2 m cowpea strip width (W2) produced grain yield similar to that from sole maize (W1) but significantly higher than a 3 m maize strip width and 3 m cowpea strip width system (W3) and a 1.2 m maize strip width and 4.8 m cowpea strip width system (W4) in all the years. The average reduction in maize yields due to strip-intercropping of maize and cowpea in the W2, W3, and W4 strip-intercropping system was 4.3%, 57%, and 226%, respectively as compared to sole maize. Similar trends were also recorded for the straw yield of maize with respect to slope and strip widths.

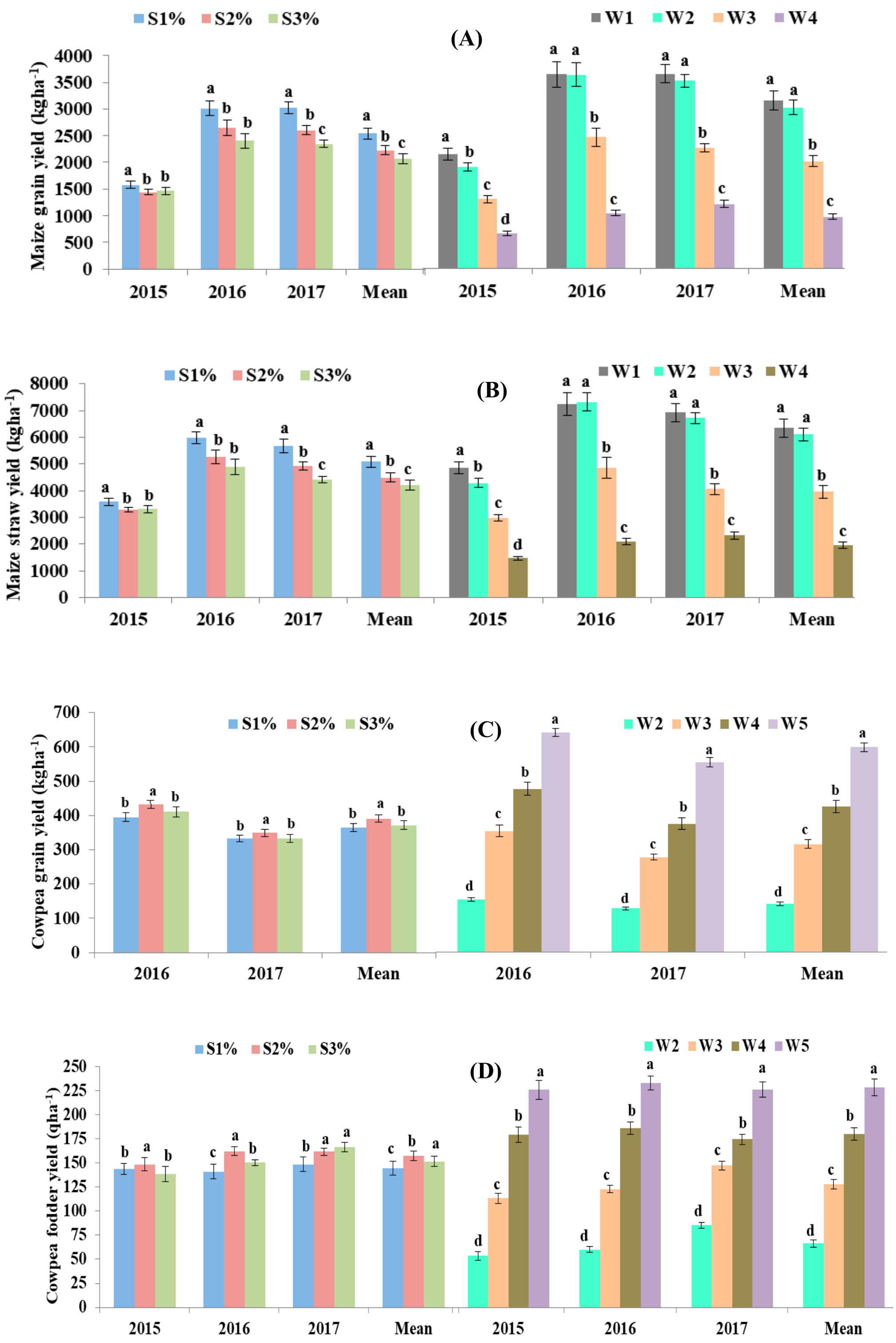

Figure 2. Effect of land slopes and strip width on (**A**) maize grain yield; (**B**) maize straw yield; (**C**) cowpea grain yield and (**D**) cowpea fodder yield. Different letters on standard error bars indicate significant differences at $p < 0.05$ between different treatments within a year according to the least significant difference (LSD) test. S1%: 1% Slope, S2%: 2% Slope, S3%: 3% Slope, W1: Sole maize (60 cm × 20 cm), W2: Maize strip 4.8 m + Cowpea strip 1.2 m, W3: Maize strip 3 m + cowpea strip 3 m, W4: Maize strip 1.2 m + cowpea strip 4.8 m and W5: Sole cowpea (at 30 cm row to row spacing).

3.1.2. Cowpea

In 2015, due to prolonged dry spell, cowpea grain yield was not obtained and the crop was harvested as fodder. The land slope had a significant influence on the cowpea grain yields during 2016 but not in 2017. The mean grain yield of cowpea was highest on the 2% slope (391 kg ha^{-1}) and it was 7% and 5% higher than the grain yield recorded on the 1% slope (364 kg ha^{-1}) and 3% slope (372 kg ha^{-1}), respectively. Cowpea grain yield from W5 plots was significantly higher than the maize and cowpea strip intercropping systems. However, the cowpea grain yield on a proportionate basis in the W2 and W3 strip-intercropping system was higher than the W4 and sole cowpea (W5). Growing of cowpea on the 2% land slope showed higher fodder yield than the 1% and 3% land slope in 2015 and 2016 but in 2017, cowpea fodder yield on the 3% land slope was the highest. The mean cowpea fodder yield on the 2% slope was 8.2% and 3.8% higher over the 1% slope and 3% slope, respectively. Fodder yield of sole cowpea was significantly higher in the maize and cowpea strip intercropping systems in all the years.

3.2. Maize Equivalent Yield (MEY) and Land Equivalent Ratio (LER)

3.2.1. Maize Equivalent Yield

A better representation of yields of component crops in intercropping/strip-intercropping system is by estimating the equivalent yield of the dominating crop, i.e., maize equivalent yield (MEY). Maize equivalent yield on the 1% slope was significantly higher than the 2% and 3% slope in all the years except in 2015 (Figure 3). The mean value of MEY on the 1% slope was 5.4 and 11.2% higher yield over the 2% slope and 3% slope, respectively. Among maize and cowpea sole cropping and maize and cowpea strip-intercropping systems, the W2 system resulted in significantly higher MEY than sole maize and other maize and cowpea strip-intercropping systems in 2016. In 2015 and 2017, MEY in the W2 system was at par with sole maize (W1) but significantly higher yield over all sole and maize and cowpea strip-intercropping systems. On a mean basis, the W2 system resulted in 11.6, 12.1, 28.6, and 41.2% higher MEY over sole maize, W3, W4, and sole cowpea, respectively. On all the land slopes, the highest MEY was recorded under maize and cowpea strip-intercropping system having 4.8 m maize strip width and 1.2 m cowpea strip width. (Figure 4).

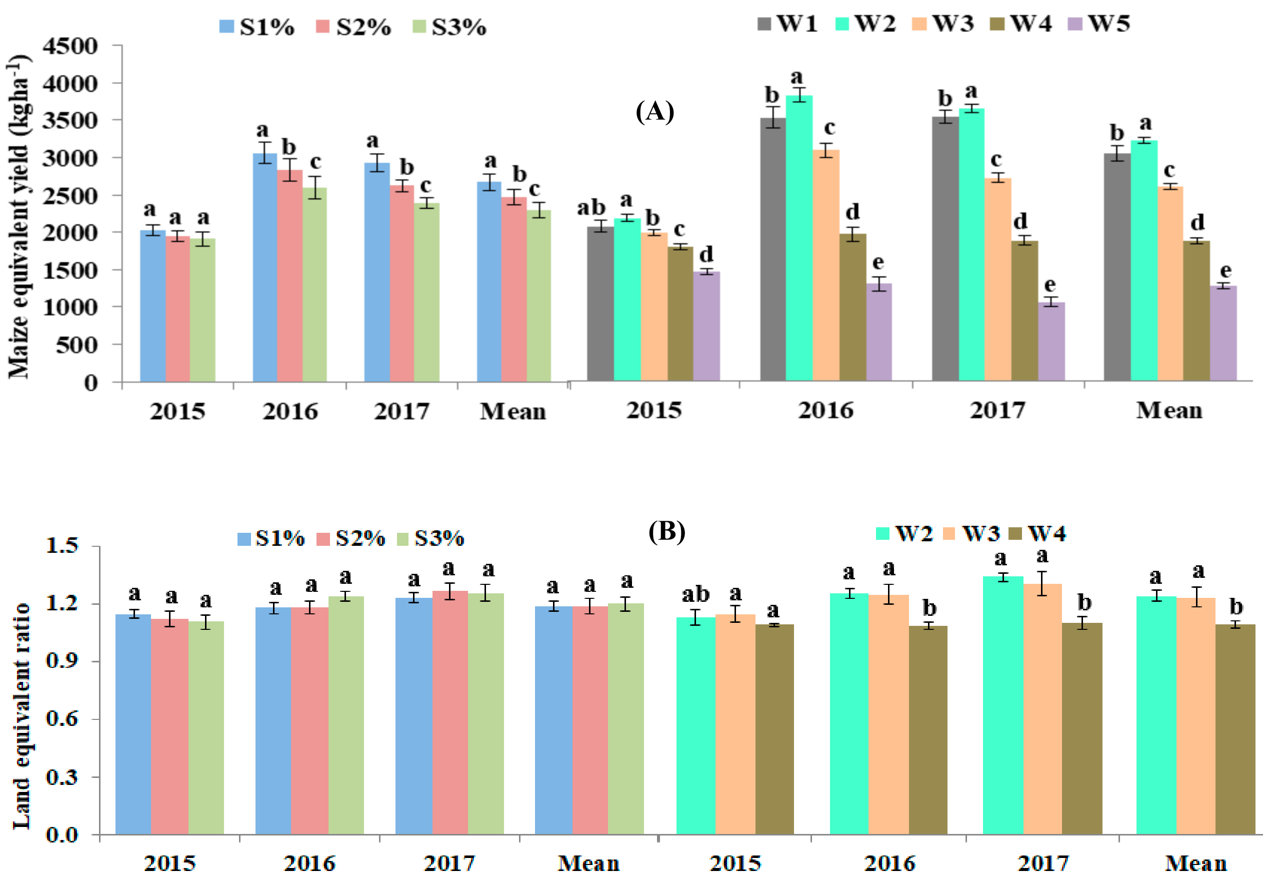

Figure 3. Effect of land slopes and strip width on (**A**) maize equivalent yield and (**B**) land equivalent ratio. Different letters on standard error bars indicate significant differences at $p < 0.05$ between different treatments within a year according to the LSD test.

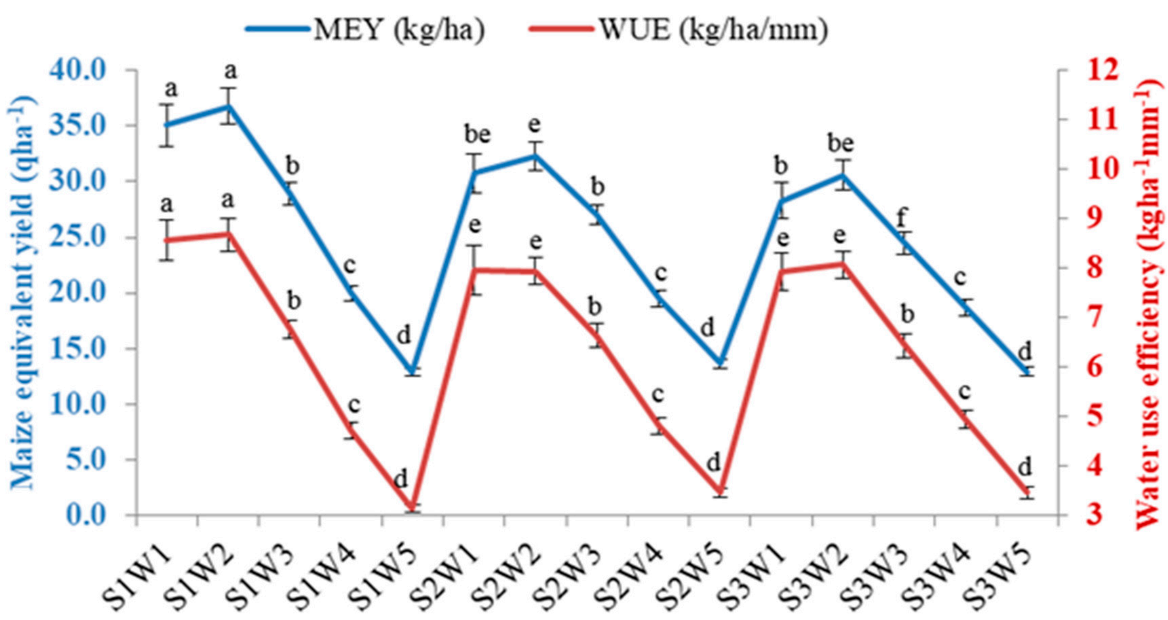

Figure 4. Combined effect of land slopes and strip width on maize equivalent yield and water use efficiency. Different letters on standard error bars indicate significant differences at $p < 0.05$ between different treatments within a year as per the ANOVA procedures of RBD analysis.

3.2.2. Land Equivalent Ratio (LER)

LER indicates the relative land area under the sole crop required to produce the yield as obtained from the intercropping system. LER is the most important parameter to evaluate the intercropping system. If the LER value is >1, then intercropping is beneficial. The effect of land slopes on the LER values was not significant in all the years. In the maize and cowpea strip-intercropping system, the LER values varied from 1.13 to 1.34 for W2, from 1.15 to 1.31 for W3, and from 1.09 to 1.10 for W3. The LER value exceeded unity in all the systems, indicating yield advantage in strip-intercropping. The 3-year mean value of the LER was the highest (1.24) in the W3 strip-intercropping system, indicating a 24% yield advantage over sole cropping systems of maize and cowpea.

3.3. Leaf Area Index (LAI)

The effect of land slopes on the leaf area index of maize and cowpea was significant. The highest LAI of maize and cowpea was measured on the 1% slope at 30 DAS and it was significantly higher than S2 and S3 (Figure 5). Among the maize and cowpea strip-intercropping systems, the W4 strip-intercropping system recorded the maximum leaf area index of maize and cowpea at 30 DAS than W1, W2, W3, and W4 systems. Among sole crops, sole cowpea provided maximum ground cover which was significantly higher than sole maize and maize and cowpea strip-intercropping systems.

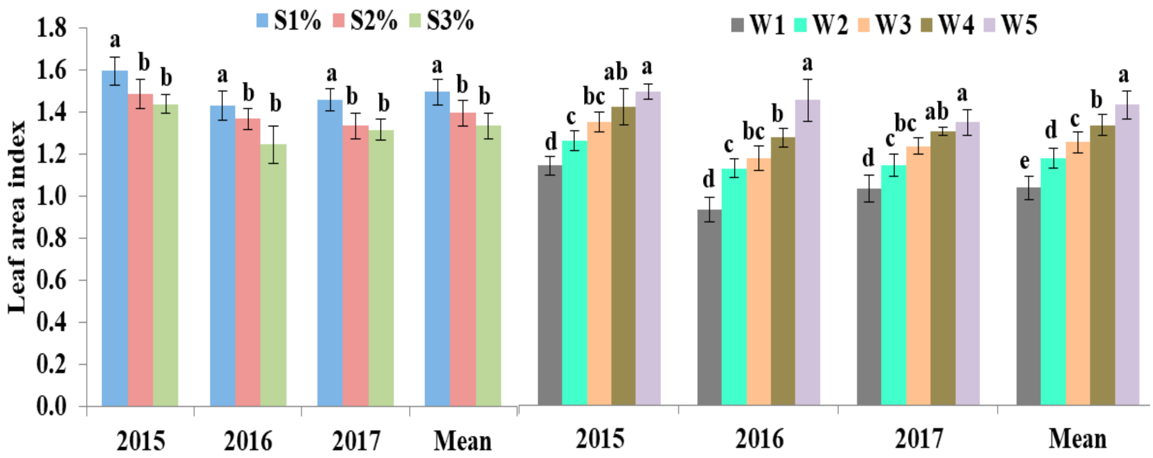

Figure 5. Effect of land slopes and strip width on leaf area index 30DAS. Different letters on standard error bars indicate significant differences at $p < 0.05$ between different treatments within a year according to the LSD test.

3.4. Resource Conservation

3.4.1. Runoff and Soil Loss

During three years of experimentation, 23–26 runoff events (6 in 2015, 8 in 2016, and 12 in 2017) were observed. A higher number (26) of runoff events were recorded from the 3% slope, 2% slope, and from sole maize plots and less (23) from the 1% slope, sole cowpea, and maize and cowpea strip-intercropping systems. Among all the land slopes, higher runoff (27.8–31.5%) and soil loss (7.01–9.79 Mg ha^{-1}) were recorded on the 3% slope followed by the 2% slope (23.1–26.5 % and 5.6–8.0 Mg ha^{-1}) and the 1% slope (19.8–23.0% and 3.75–5.74 Mg ha^{-1}). The average soil loss of 3 years on the 3% slope was 3.60 Mg ha^{-1} and 1.51 Mg ha^{-1} more than on the 1% slope and 2% slope (Figure 6). Strip-intercropping of maize and cowpea resulted in a significant reduction in runoff and soil loss as compared to sole maize. The W4 strip-intercropping system showed the highest reduction in runoff and soil loss which was at par with that under the W3 system but significantly higher than the W2 system. Among sole crops, higher runoff (28.1–31.0%) and soil loss (6.21–9.25 Mg ha^{-1}) were recorded in sole maize and lowest (21.3–24.3% and 4.92 to 6.89 Mg ha^{-1}) in the sole cowpea. This indicates the need for devising suitable conservation measures to check soil loss from undulating sloppy fields.

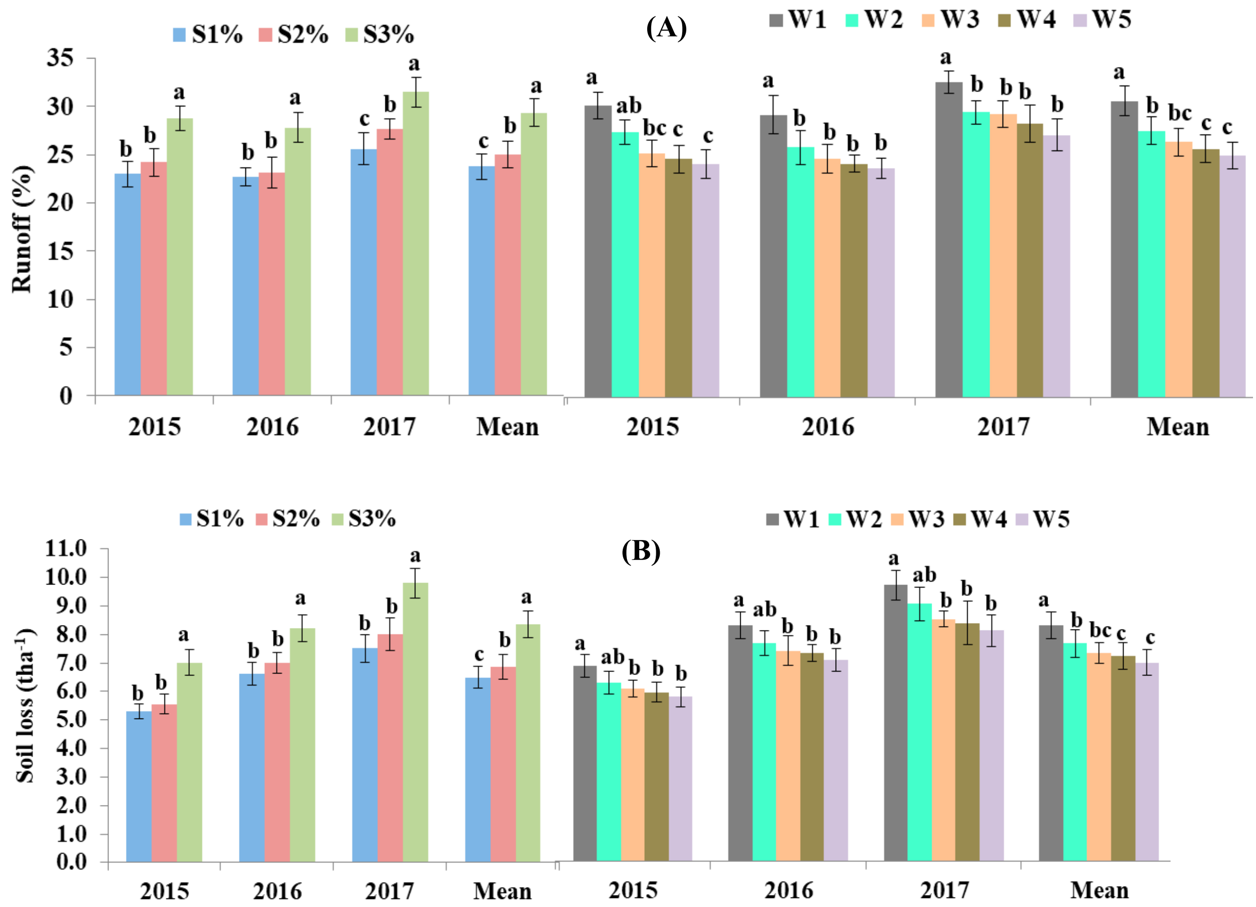

Figure 6. Effect of land slopes and strip width on (**A**) run-off and (**B**) soil loss. Different letters on standard error bars indicate significant differences at $p < 0.05$ between different treatments within a year according to the LSD test.

3.4.2. Nutrient Loss

During three years of experimentation, higher N, P, K, and organic carbon (OC) loss through runoff was observed in 2017 and lower in 2015. Among the slopes, average N, P, K, and OC loss in 3 years were lowest on the 1% slope and highest on the 3% slope (Figure 7). The nutrient loss on the 3% slope was significantly higher than on the 1% and 2% slope during all the years. On the 3% slope, the average loss of N, P, and K was 3.80, 1.82, and 4.10 kg ha^{-1} respectively more than that on the 1% slope. The average loss of N on the 3% slope was 3.8 and 2.8 kg ha^{-1} more than that on the 1% and 2% slope, respectively. Similarly, average P and K loss on the 3% slope was 6.15 kg ha^{-1} and 17.6 kg ha^{-1} respectively with corresponding values of 4.33 kg ha^{-1} and 17.1 kg ha^{-1} on the 1% slope and 4.85 kg ha^{-1} and 18.5 kg ha^{-1} on the 2% slope. The average organic carbon loss on the 3% slope was 21% and 19% more than on the 1% and 2% slope. Nutrient losses were significantly affected by different strip-intercropping systems. Among the sole crops, loss of N, P, K, and OC in runoff was lowest in W5 and highest in W1. In strip-intercropping systems, loss of N, P, K, and OC decreased with the increase in cowpea strip width. The highest loss of N, P, K, and OC were observed in the W2 system followed by W3 and W4. The W4 strip-intercropping system resulted in a significant reduction in N, P, K, and OC loss as compared to the W2 and W3 systems. The organic carbon loss in sole maize was significantly higher than W2, W3, W4, and W5 by 16%, 32%, 43%, and 56%, respectively. Interaction between slope and maize and cowpea strip width was significant for N, K, and organic carbon loss. Sole cowpea resulted in a minimum loss of N, K, and organic carbon on the 1%, 2%, and 3% slopes (Figure 8). On all the land slopes, maize and cowpea strip-intercropping systems showed a significant reduction in N, K, and organic carbon loss as compared to sole maize.

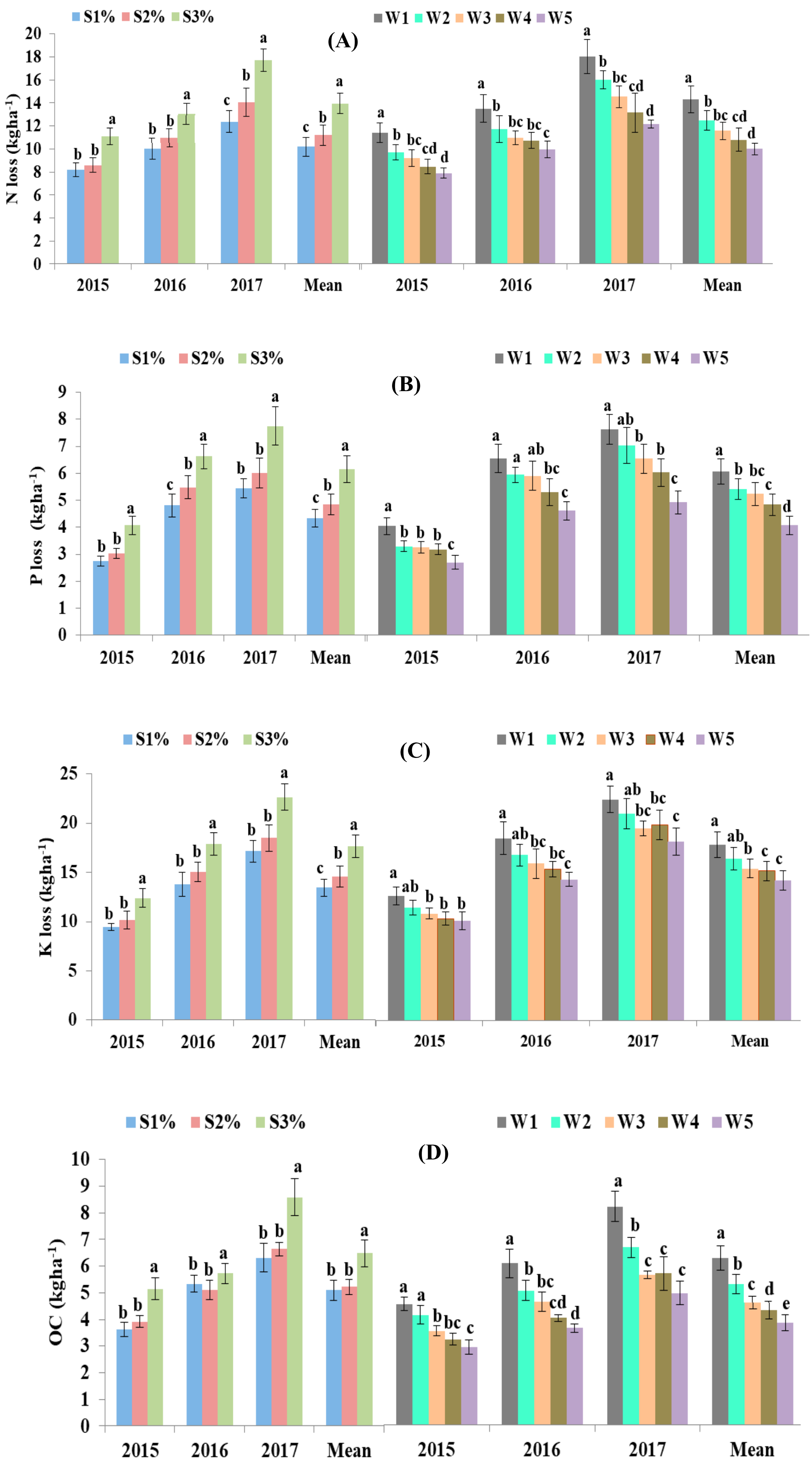

Figure 7. Effect of land slopes and strip width on (**A**) N loss; (**B**) P loss; (**C**) K loss and (**D**) organic carbon loss. Different letters on standard error bars indicate significant difference at $p < 0.05$ between different treatments within a year according to the LSD test.

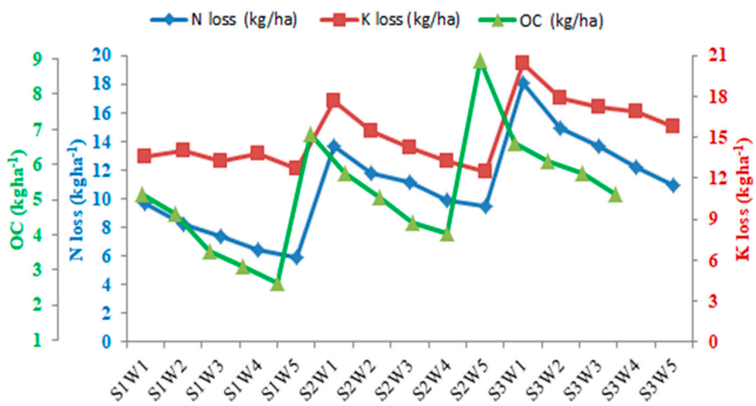

Figure 8. Combined effect of land slopes and strip width on N loss, organic carbon loss, and K loss.

3.4.3. Water Conservation Efficiency and Water Use Efficiency

The water conservation efficiency (WCE) varied significantly among the slopes. The highest water was conserved on the 1% slope (77.0–80.2%) which was significantly higher than the 2% slope (73.5–76.9%) and 3% slope (68.5–72.2%) (Figure 9). Among the sole crops and strip-intercropping systems, the highest WCE (75.7–78.7%) was recorded under sole cowpea and the lowest in sole maize (69.0–71.0%). While the W3 and W4 strip-intercropping systems showed the WCE at par with sole cowpea and significantly higher than sole maize indicating better water conservation under these treatments. Crop WUE on the 1% slope was 3.5% and 3.4% higher than on the 2% and 3% slopes. The WUE in the W2 strip-intercropping systems was 24% and 70% greater than the W3 and W4 strip-intercropping systems.

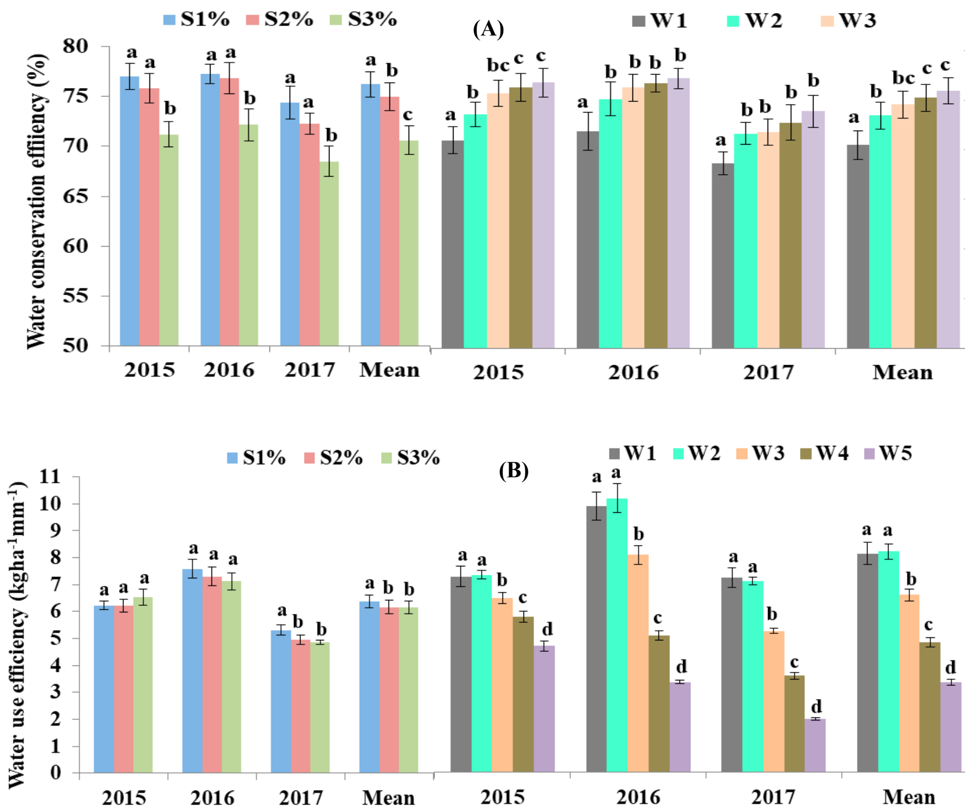

Figure 9. Effect of land slopes and strip width on (**A**) water conservation efficiency and (**B**) water use efficiency. Different letters on standard error bars indicate significant differences at $p < 0.05$ between different treatments within a year according to the LSD test.

3.5. Profitability

Among all the slopes, the average cost of cultivation was highest on the 1% slope than the 2% and 3% slopes. The highest gross returns (US$ 858 ha^{-1}) obtained on the 1% slope were higher than the gross returns obtained on the 2% and 3% slopes by US$ 809 ha^{-1} and US$ 764 ha^{-1}, respectively. Similarly, the highest net returns (US$ 428 ha^{-1}) recorded on the 1% slope were higher by US$ 45 ha^{-1} and US$ 88 ha^{-1} over the 2% and 3% slopes. The highest BC ratio of 2.00 was estimated on the 1% slope followed by 1.90 on the 2% slope and the lowest (1.80) on the 3% slope. During all the 3 years of experimentation, among the sole cropping and maize and cowpea strip-intercropping systems, the highest expenditure and net returns were in the W2 system followed by the W1, W3, W4, and the lowest in W5. The W2 system also fetched the highest net returns of US$ 530 ha^{-1} which was higher over W1, W3, W4, and W5 treatments by US$ 98.7, US$ 91.9, US$ 224, and US$ 317 ha^{-1}, respectively. The maize and cowpea strip-intercropping in 4.8 m:1.2 m (W2) resulted in the highest mean BC ratio of 2.09 followed by 1.99 in W3, 1.99 in W1, 1.77 in W4, and 1.64 in W5 (Table 1).

Table 1. Economics (mean of three years) of strip-cropping maize + cowpea on different slopes.

Slope	Cost of Cultivation (US$ ha^{-1}) *	Gross Returns (US$ ha^{-1}) **	Net Returns (US$ ha^{-1})	B:C
S_1: 1%	429	858	428	2.00
S_2: 2%	426	809	384	1.90
S_3: 3%	424	764	340	1.80
		Maize + Cowpea strip-intercropping		
W_1: 6:00	470	901	432	1.92
W_2: 4.8:1.2	488	1018	530	2.09
W_3: 3:3	443	881	439	1.99
W_4: 1.2:4.8	397	704	306	1.77
W_5: 0:6	333	546	214	1.64

* 1 US $ = 66 INR. Prices (US $) of inputs (tonne or unit): urea 95; Single super phosphate 124; muriate of potash 255; maize seed 2652; cowpea seed 909; atrazine 5606; decis 9091; man labour (8 h) 4.4; land preparation ha^{-1} (one ploughing and two harrowing) 95.5. ** Prices (US $) of outputs (tonne): maize grain 253; cowpea grain 530; maize straw 15; Cowpea fodder 15.

4. Discussion

In general, during three years of experimentation (2015–2017), the highest maize grain yield (Figure 2) was recorded in the second year (2016) which can be due to the optimum and well-distributed rainfall (509 mm rainfall in 25 rainy days with only two rainy days of more than 50 mm rainfall) during the entire crop duration. The lowest grain yield of maize was observed in the first year (2015) due to the prolonged dry spell of 28 days from 21 August to 19th September starting from silking to dough stage. In 2015, due to the poor pod formation in cowpea, it was used as fodder, and grain yield was not recorded. The large variation in productivity of maize and cowpea in different years indicates that rainfall amount and its distribution have a considerable effect on crop performance. The findings of our study indicate that on the 1% and 2% slope, sole maize can be cultivated but on the 3% slope, cultivation of sole maize may cause significant runoff, soil loss, and nutrient loss. Therefore, on the sloppy field with the 3% slope, strip-intercropping of maize and cowpea should be practiced. This information on strip-intercropping of maize and cowpea on undulating land is beneficial to develop management strategies for sustaining the crop productivity in the *Shivalik* foothills of India, and other regions of the world with undulating topography [36,47–51].

4.1. Maize and Cowpea Productivity from 2015 to 2017

Maize grain yield obtained on the 1% slope was significantly higher than on the 2% slope and 3% slope and yield depicted a declining trend with increase in slope except in 2015. This might be due to the fact that on steep slopes there is a greater runoff and soil loss, which is characterized by a thinner surface horizon and lower infiltration rate resulting in lower soil productivity [52]. Soil erosion reduces crop growth and yield as it influences many soil properties such as thinning of topsoil, reducing water-stable aggregates, increasing soil bulk density, reducing water holding capacity, and reducing soil organic matter and nutrient content [53]. Wezel et al. [54] and Hoang et al. [55] reported a decrease in maize yield on sloppy fields as a result of the decrease in soil fertility due to soil erosion. Maize grain yield responded significantly to strip width. Sole maize yield varied from 2137 kg ha^{-1} in 2015 to 3645 kg ha^{-1} in 2017. The strip-intercropping combination of 4.8 m maize and 1.2 m cowpea (W2) produced grain yield similar to that from sole maize (W1) grown in 6 m strip but significantly higher than maize and cowpea strip-intercropping in 3:3 m (W3) and maize and cowpea strip-intercropping in 1.2:4.8 m (W4) in all the years. In spite of 20% less plant population, the W4 system produced only 4% less yield than sole maize. These benefits were attributed to reduced intraspecific competition among maize plants due to an increase in the number of border rows which benefits from more light interception and increased availability of nitrogen from the companion legume crop [56,57].

The grain yield of cowpea was highest when raised on the 2% slope followed by the 3% slope and the 1% slope. This might be due to the fact that on 2% slope and 3% slope, good drainage conditions ensured adequate plant growth resulting in higher seed yield [58]. Moreover, cowpea plants may have been suppressed due to the more vigorous growth of maize plants on the 1% slope [33]. Cowpea grain yield from sole cowpea (W5) plots was significantly higher than maize and cowpea strip intercropping systems. This is due to the 20%, 50%, and 80% less plant population in W4, W3, and W2 strip intercropping systems, respectively as compared to sole cowpea [59].

4.2. Runoff and Soil Loss

On sloppy arable lands, soil disturbance for agriculture operations accelerates the runoff and soil erosion [60,61]. In our study, higher runoff (27.8–31.5%) and soil loss (7.01–9.79 Mg ha^{-1}) was recorded on the 3% slope followed by the 2% slope (23.1–26.5% and 5.55–8.00 Mg ha^{-1}) and 1% slope (19.8–23.0% and 3.75–5.74 Mg ha^{-1}). This is due to the fact that on sloppy fields, water runs off quickly as the infiltration opportunity time is less. As runoff velocity increases, so does its ability to detach and transport the sediments. On flat or gently sloping land, a film of water forms on the surface during intense storms which helps to dissipate raindrop energy. Therefore, the slope is one of the most important factors in water erosion as it affects both the amount, as well as the velocity, of runoff [62]. Strip-intercropping of maize and cowpea resulted in a significant reduction in runoff and soil loss as compared to sole maize. The highest reduction in runoff and soil loss was achieved in a maize strip 1.2 m wide and cowpea strip 4.8 m wide and it increased with the reduction in the cowpea strip width. Strip-intercropping of maize with cowpea decreased runoff in all the strip-intercropping systems which can be attributed to the fact that cowpea quickly establishes a very good canopy cover which dissipates the rainfall impact thereby resulting in lower runoff [63]. The results are in agreement with the published literature [37,51], which reported that lower soil erosion losses were observed under soybean than those under widely spaced maize.

4.3. Nutrient Losses

Higher loss of N, P, K, and OC was observed on the 3% slope than on the 2% slope and 1% slope. This could have resulted from higher runoff and soil loss on the 3% slope. N which is generally soluble in water has been lost in runoff water while P, K, and OM which are adsorbed on the soil particles might have been carried away with soil aggregates in the runoff water [60]. Maximum losses of N, P, K, and OC were recorded in sole maize cultivation and the lowest in sole cowpea during 2015, 2016, and 2017. The reason ascribed is that maize is an erosion permitting crop due to wide row spacing and low leaf area per unit ground area as compared to cowpea which covers the soil surface quickly and maintains a high leaf area index throughout its growth period. Similarly, Singh et al. [51], Prasad et al. [64], and Lakaria et al. [65] reported higher losses of organic carbon, N, P, and K total nitrogen in maize and castor, whereas losses were less in groundnut.

4.4. Regression and Correlation Analysis

Regression relationships between runoff and soil and nutrient loss are depicted in Figure 10. Relatively higher R^2 values suggest that the coefficient for loss of soil and nutrients is greater for higher surface runoff. The plots with greater slope and maximum maize strip width resulted in greater soil nutrient loss as depicted from regression analysis.

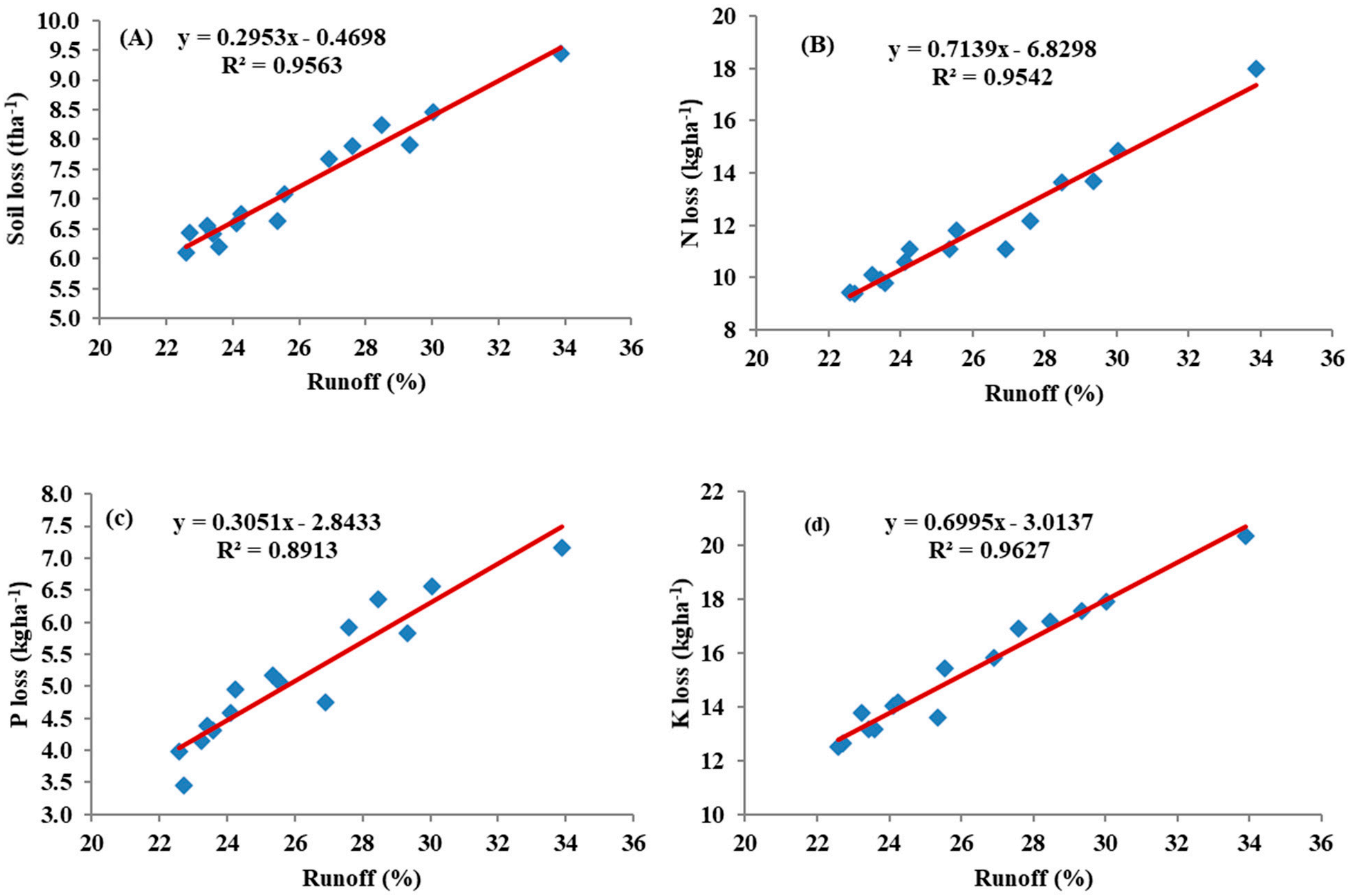

Figure 10. Regression relationship between (**A**)runoff and soil loss; (**B**) runoff and N loss; (**C**) runoff and P loss; (**D**) runoff and K loss.

A positive and strongly significant correlation (Table 2) was observed between runoff and soil and nutrient loss (NPK) suggesting that greater runoff not only erodes the soil but also results in higher dissolution of nutrients which has a perilous impact on soil fertility. Yao et al. [66] also confirmed that the relationship between runoff and nutrient loss was positively significant. A negative and significant correlation was observed between cowpea yield and nutrient loss (Table 2) indicating that a decrease in soil nutrients due to erosion impairs crop performance through reduced underground and aboveground biomass.

Table 2. Pearson's correlation among studied parameters.

	Rainfall	Runoff	Soil Loss	N Loss	P Loss	K Loss	Maize Grain Yield	Cowpea Grain Yield	Maize Straw Yield	Cowpea Straw Yield
Rainfall	1									
Runoff	0.05	1								
Soil loss	0.01	0.97 **	1							
N loss	0.06	0.97 **	0.95 **	1						
P loss	0.16	0.94 **	0.92 **	0.94 **	1					
K loss	0.08	0.98 **	0.98 **	0.96 **	0.93 **	1				
Maize grain yield	0.49	0.40	0.28	0.47	0.51	0.36	1			
Cowpea grain yield	−0.37	−0.57 *	−0.44	−0.63 *	−0.63 *	−0.52 *	−0.96 **	1		
Maize straw yield	0.49	0.41	0.28	0.48	0.52 *	0.37	0.99 **	−0.96 **	1	
Cowpea fodder yield	−0.34	−0.57 *	−0.43	−0.62 *	−0.61 *	−0.51 *	−0.95 **	0.99 **	−0.95 **	1

** Significant at 0.01 probability level, * significant at 0.05 probability level.

5. Conclusions

The results from this 3-year field study indicate that the cultivation of maize and cowpea on the 1% slope and 2% slopes, respectively resulted in the highest yield. Runoff, soil and nutrient losses were higher on the 3% slope as compared to the 1% and 2% slopes. The adoption of the strip-intercropping system with a 4.8 m maize strip width and 1.2 m cowpea strip width showed significantly higher maize equivalent yield than sole maize and other maize and cowpea strip-intercropping systems and also has the highest LER value (1.24) indicating a 24% yield advantage over sole cropping systems of maize and cowpea. This system also reduced runoff and soil loss by 10.9% and 8.3%, respectively than sole maize crop. On sloping land, the maize and cowpea strip-intercropping system enhanced water use efficiency by 12.3% and increased maize equivalent yield by 19.4% as compared to sole cropping of maize and cowpea. Hence, the strip-intercropping of maize and cowpea should be practiced in the *Shivalik* foothills of Northwest India in order to ensure sustainable crop production vis-à-vis resource conservation.

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