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Intervention of Climate-Smart Practices in Wheat under Rice-Wheat Cropping System in Nepal

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Abstract: Besides a proper agronomic management followed by Nepalese farmers, wheat (*Triticum aestivum* L.) production has been severely affected by changing climate. There are many interventions, including climate-smart practices, to cope with this situation and possibly enhance crop and soil productivity. Field experiments were set up in a randomized complete block design with six treatments (TRT) with four replications in three locations (LOC) during wheat-growing seasons in Nepal from 2014 to 2016. Treatments included (i) Controlled Practice (CP), (ii) Improved Low (IL), (iii) Improved High (IH), (iv) Climate Smart Agriculture Low (CSAL), (v) Climate Smart Agriculture Medium (CSAM), and (vi) Climate Smart Agriculture High (CSAH), whereas those LOC were Banke, Rupandehi and Morang districts. There was a significant main effect of TRT and LOC on grain yield and a significant interactionn effect of TRT × LOC on biomass yield in 2014–2015. About 55.5% additional grain yield was produced from CSAM treatment compared to CP in 2014–2015. Among locations, grain yield was the highest in Banke (3772.35 kg ha^{-1}) followed by Rupandehi (2504.47 kg ha^{-1}) and Morang districts (2504.47 kg ha^{-1}). In 2015–2016, there was a significant interaction effect of TRT × LOC on grain and biomass yields. The highest grain yield was produced from CSAH treatment in Banke district in 2015–2016. Overall, grain yield and other parameters showed a better response with either of the climate-smart interventions (mostly CSAH or CSAM) despite variability in geography, climate, and other environmental factors indicating the potential of climate-smart practices to improve wheat production in southern plains of Nepal.

Keywords: climate-smart agriculture; crop residue; crop sensor; Nepal; tillage; wheat

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1. Introduction

Wheat (*Titicum aestivum* L.) is an important food crop in Nepal in terms of production, consumption, and economic contribution. In 2018/2019, wheat was cultivated in 0.7 million hectare (ha) and produced 2 million metric ton (MT) of grains, which corresponds to around 20 and 19% of total cultivated area and total production of all food crops, respectively [1]. Despite the increase in cultivated area and total production of wheat in Nepal, the productivity is lower as compared to other neighboring countries [2]. There exists a large yield gap in wheat production due to several constraints in agronomic practices including but not limited to unavailability of quality inputs, nutrient management, disease-pest management, etc. [3–5]. However, the demand for wheat is ever increasing. Hence, it is important to develop effective strategies to minimize the yield gap by improving the wheat production practices.

The rapidly changing climate is imposing serious threats to overall agricultural production [6,7]. The increase in temperature can have both positive and negative impacts, however, the negative effects of increasing temperatures and drought are likely to dominate the benefits [8]. Studies in the past have shown decline in production of cereal crops, mainly attributed to increasing water stress that resulted from rising temperatures and reduced rainy days [9,10]. In particular, the variability in productivity of wheat has been found to be largely dependent on the changes in climate parameters [11]. Abnormal changes in temperature and precipitation and the occurrence of extreme events have direct impacts on wheat growth and performance [12–14]. Studies have predicted that there might be around 10–50% reduction in wheat yield by 2100 due to the changed climate if no adaptation or mitigation measures are taken [15,16]. Adaptation strategies, which involve series of climate-smart practices like crop, land, nutrient, and water management, can minimize the impact of climate change in farming and crop overall production system.

Climate-smart practices in agriculture can ensure the crop production from the adverse effects of climate change and potentially improve the yield. Adaptation to impacts of climate change is an important pillar of climate-smart agriculture [17–19]. The criteria of adaptation techniques include nutrient smart and water smart practices, among others [19]. Several improvements in agronomic practices have been carried out to make agriculture nutrient smart, for example Jholmal (locally prepared bio-fertilizer) [20] and water smart [21] practices. As a water smart practice, reduced tillage such as no-till and minimum tillage are being practiced. Reduced tillage has the advantage of moisture retention [22,23], less damage to soil physical properties [24,25], etc. over the conventional tillage. Incorporation of crop residue from the previous season is another practice for moisture conservation in water smart practice [26]. Similarly, nutrient management decision support tools, for example, Soil Plant Analysis Development (SPAD) meter, leaf color chart (LCC) and optical sensors have been devised and practiced for in-season nitrogen (N) management [27–30]. Wheat production is largely varied among different practices of tillage [31], nutrient management [32], crop residue management [33], etc. These improvements in agronomic practices to better adapt the changing climate may be a potential strategy to elevate the wheat production hit by the impacts of climate change.

Although there are several interventions in practice to combat against the impacts of climate change and potentially enhance crop and soil productivity, research on the integrated approach of climate-smart interventions is still negligible in Nepal. Understanding the effectiveness of different climate-smart practices in improving the wheat yield in a changing climatic condition of Nepal is important from both the production and policy perspective. Exploration of simple interventions and technology that can be adapted by small holders' farmers in developing countries with limited resources and technology is important. Therefore, the current study aimed to explore an effective package of climate-smart practices that can be farmer friendly to the wheat growers thriving in most vulnerable climates of southern plains of Nepal and other similar regions around the globe.

2. Materials and Methods

2.1. Study Location

Based on geographical structure, Nepal is divided into three ecological regions: Terai (lowland), hills (mid hill), and mountains (upland) [34]. Terai region, where the experimental sites were located, is the grain basket of the country and produces 57% of the total national wheat production [1]. The three different research locations were purposively selected across east-west southern plains (Terai) of Nepal, which were in (i) Khajura rural municipality of Banke district (28°06′45.9″ N 81°32′59.2″ E), (ii) Rohini rural municipality of Rupandehi district (27°32′19.2″ N 83°32′56.3″ E) and (iii) Biratnagar metropolitan city of Morang district (26°31′13.9″ N, 87°15′53.2″ E). The elevation of study area was 181, 110 and 81 m above mean sea level in Banke, Rupandehi and Morang districts, respectively. The research locations represent a distinct east west variability in climate, soil and geography of typical wheat growing belt in Nepal (Figure 1).

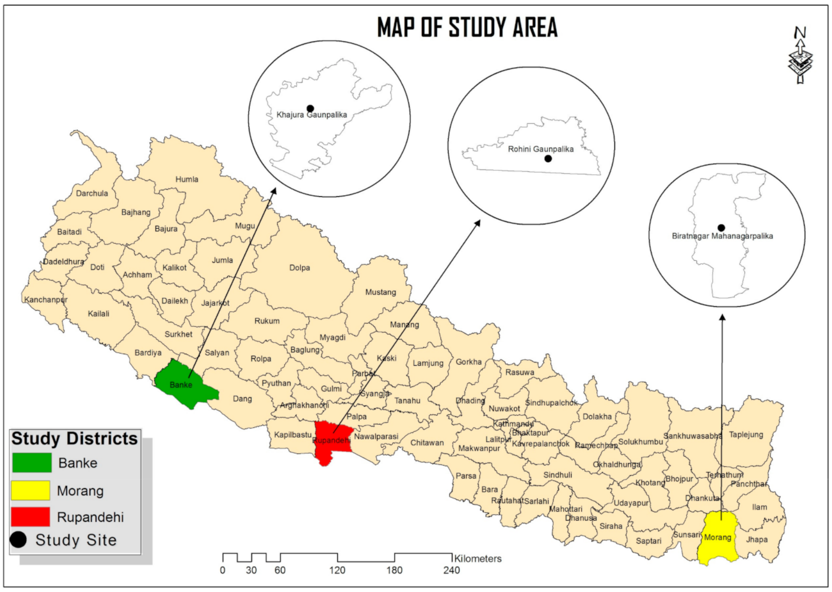

Figure 1. Map of Nepal showing research sites in Banke, Rupandehi and Morang districts.

Rice (*Oryza sativa)* is typically cultivated during the monsoon season, while maize (*Zea mays)* and wheat are mostly sown during the drier periods before or after the monsoon. Maize and wheat are mostly grown under rainfed conditions and with very little use of commercial fertilizers. Rice–wheat and maize–rice-based farming systems are common in Terai region of Nepal, and a similar cropping system is dominant in all study areas.

2.2. Climate

Based on the modified Koppen–Geiger climate classification system, Terai region of Nepal experiences a tropical savanna climate type with dry winters and hot summers and a mean annual temperature of 20–28 °C [35]. The country receives most of the total annual rainfall (70–90%) during the rice-growing season (monsoon) i.e., from June to September, while winter months mostly remain cool and dry [36]. The agriculture system here is mostly rainfed with irrigation provided for winter crops in geographically feasible areas. There is a gradual decrease in rainfall as we go from eastern to western regions, which is due to two major weather systems (southwest monsoon and southwest disturbances) dominating the rainfall events [37].

The temperature and precipitation data were collected from Regional Agriculture Research Stations (RARS), Banke, RARS Sunsari (the adjoined district of Morang) and National Wheat Research Program (NWRP) Rupandehi. Since the research fields were located at close vicinity to these research stations in the respective districts, the weather data reflects their micro climatic conditions. During the crop-growing period (November to April 2014/2015 and 2015/2016), the averaged maximum temperature ranged between 15 and 40 °C with the highest temperature during the month of April and minimum temperature ranged between 7 and 21 °C and was at its lowest during January. In both years, the annual average rainfall was highest in Morang (2031 mm in 2015 and 2304 mm in 2016) followed by Rupandehi (1416 mm in 2015 and 1864 mm in 2016) and Banke districts (1087 mm in 2015 and 817 mm in 2016).

2.3. Soil

Soil sampling from experimental fields was carried out in 2014 before sowing wheat in all locations. A hand auger was used for soil sampling. Samples were collected from five random spots in a diagonal pattern from the experimental field at each study location and composited to a single sample for analysis. Soils from the top 20 cm were analyzed for soil texture; bulk density; pH; and OM, N, P, and K concentration, by following a standard lab procedure. Soils in the current study locations varied in texture from clay loam in Banke, loam in Rupandehi to the silty loam in Morang district. The average bulk density was around 1.4 g cm^{-3}, except in the Banke district it was 1.5 g cm^{-3}. Based on the ratings table presented by Panday et al. [38], the nutrient status ratings are indicated beside the values in Supplementary Table S1, where soil pH ranged from slightly acidic to neutral (only in Banke district). Organic matter and total N were at low and very low levels in all three locations, respectively. The available P ranged from very low, medium and high in Banke, Rupandehi and Morang districts, respectively. Available K was at medium level in all three locations.

2.4. Experimental Design and Treatment

The current experiment was conducted in a Randomized Complete Block Design with six treatments and four replications in each geographic location. The treatments were designed based on the combination of agronomic practices, intercultural operation, crop residues retention, nutrient management, and tillage practices (Table 1).

Table 1. List of treatments used in this study.

Treatment	Treatments
Controlled Practice (CP)	Conventional tillage + Fertilizer (Farmer practice) + No residue + No Green manuring
Improved Low (IL)	Conventional tillage + Fertilizer (Farmer practice) + Residue + No green manuring
Improved High (IH)	No tillage + Fertilizer (Farmer practice) + Residue + Green manuring
Climate Smart Agriculture Low (CSAL)	No tillage + Fertilizer (Recommended rate) + Residue + No green manuring
Climate Smart Agriculture Medium (CSAM)	No tillage + Fertilizer (based on LCC) + Residue + No green manuring
Climate Smart Agriculture High (CSAH)	No tillage + Fertilizer (based on crop sensor readings) + Residue + Green manuring

Improved wheat variety popular among the farmers (Gautam variety at Banke and Morang and Bhrikuti variety at Morang) was selected to test on different tillage and management practices. Wheat was planted during the last week of November and harvested between the first to second week of April. Around 7 t ha^{-1} biomass from previous rice crop was retained at harvest in all treatments with residue. *Sesbania* sps. (Dhaincha) was grown and incorporated in the plots before planting rice in a previous season in IH and CSAH treatments. Conventional tillage plots were ploughed twice before broadcasting seed, while seed was drilled in no-till plots.

A total of 150:60:30 NPK kg ha^{-1} was applied in controlled practice fertilizer treatments (half dose of N and full dose of P and K while planting and remaining half during the tillering stage), while 100:50:25 NPK kg ha^{-1} was applied in treatment with the recommended rate. For Leaf Color Chart (LCC) and sensor (Green Seeker from Trimble Inc., Sunnyvale, CA, USA) based treatments, a total of 85:50:25 and 110:50:25 NPK kg ha^{-1} was applied, respectively. The N rate for LCC and sensor was determined and applied based on calculations from the readings taken at crown root initiation stage (CRI) and heading stage of wheat growth. For sensor-based treatment, a response index was calculated by dividing the NDVI value from CSAH treatment plot by NDVI value from CP treatment plot. When the index value was below 0.90 (at CRI stage for the study), fertilizer was applied at 35 kg N ha^{-1}. For LCC-based treatment, 30 kg N ha^{-1} was applied when the reading was below four. For all no till treatments, DAP (18:46:0 as a source of P and N) was drilled by machine simultaneously at planting and MoP (0-0-60 as source of K) was broadcasted in line manually. DAP and MoP in conventional tilled plots and Urea (46-0-0 as source of N) in all plots were uniformly hand-broadcasted.

2.5. Data Collection

At maturity (Feekes 11.4) stage, five plants were selected randomly in each plot to measure plant height and spike length. A total of 3 m^2 area (three random squares of one meter) was hand harvested in each plot and tiller count was noted. The whole harvest was air dried, hand threshed and the parameters straw biomass and grain weight were recorded. A sub-sample of grains was analyzed for moisture, and grain yield was reported on 12% moisture basis [39]. Biomass yield was reported on as-is moisture basis. Both biomass and grain yields were then converted to ton per hectare. A random mass of wheat grain was sampled to measure thousand kernel weight (TKW) from every plot.

2.6. Statistical Analysis

Statistical analysis was carried out using R 4.0.3. Analysis of variance was performed for randomized complete block design. Duncan's Multiple Range Test (DMRT) was used to observe the least significant difference among yield and yield-attributing traits for different treatments at $p < 0.05$ level of significance. Further, ggplot2 package in R was used for a bar plot showing mean and standard errors. ArcGIS 10.5 was used to develop a map showing the location of the research sites.

3. Results

3.1. Plant Population/Tiller Per Square Meter

In both years of study, a significant interaction effect of location (LOC) x treatment (TRT) on plant population was observed (Table 2). The tiller count per square meter ranged from 92 to 205 in 2014/2015 and from 143 to 350 in 2015/2016. The CSAH treatment resulted in the highest plant population in Banke in 2014/2015 while the plant population was highest for CSAM treatment in Rupandehi in 2015/2016. Furthermore, the plant population was consistently low for CP across all locations with the lowest one in Banke in both years except for Rupandehi in 2015/2016 where IH treatment had the lowest (Figure 2).

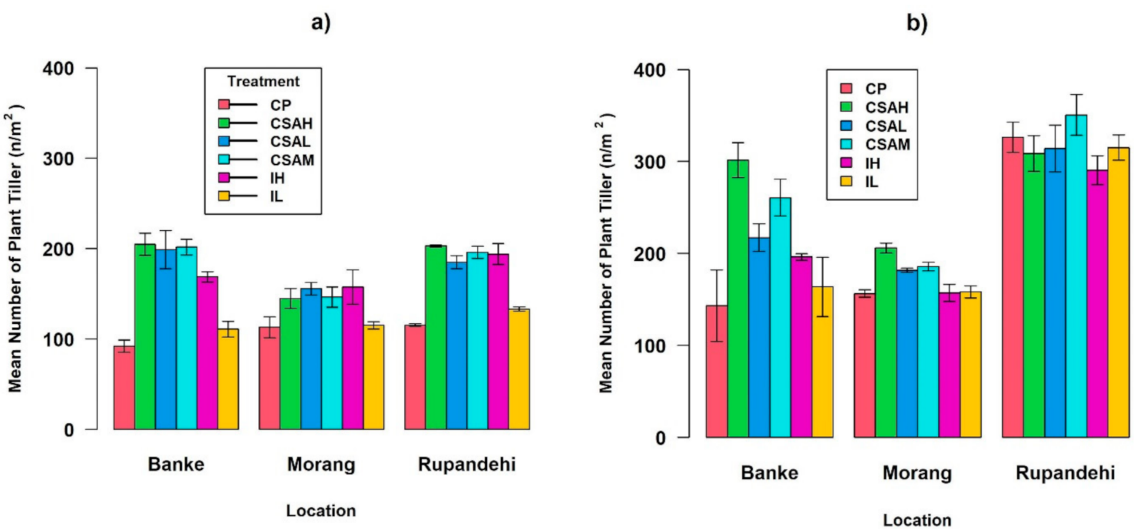

Figure 2. Number of tillers (mean ± SE) per square meter as affected by location × treatment interaction effect for wheat growing season in 2014/2015 (**a**) and 2015/2016 (**b**). Treatment included Controlled Practice (CP), Improved Low (IL), Improved High (IH), Climate Smart Agriculture Low (CSAL), Climate Smart Agriculture Medium (CSAM), and Climate Smart Agriculture High (CSAH).

Table 2. Analysis of variance (ANOVA) results with means for measured parameters as affected by location, treatments, and their interaction.

Source of Variation	Tiller	Plant Height †	Spike Length †	Grain Yield ‡	Biomass Yield ‡	Thousand Kernel Weight
Year-I						
Location (LOC)						
Banke	162.92 [a]	100.08 [a]	12.81 [a]	3772.35 [a]	7696.85 [a]	44.13 [b]
Morang	138.88 [b]	71.14 [c]	10.44 [b]	2224.94 [b]	3903.60 [b]	48.46 [a]
Rupandehi	171.13 [a]	82.74 [b]	9.52 [c]	2504.47 [b]	4169.37 [b]	36.30 [c]
Significance	***	***	***	***	***	***
Treatment (TRT)						
CP	107.00 [b]	77.75 [b]	8.43 [d]	2011.78 [b]	3890.81 [b]	42.35
IL	119.83 [b]	84.28 [a]	10.24 [c]	2567.53 [a]	4334.92 [b]	43.18
IH	173.47 [a]	84.98 [a]	11.23 [b]	3069.25 [a]	5729.42 [a]	42.99
CSAL	179.87 [a]	85.62 [a]	11.39 [ab]	3125.55 [a]	5915.44 [a]	42.72
CSAM	181.41 [a]	87.42 [a]	12.01 [ab]	3128.08 [a]	5841.67 [a]	42.99
CSAH	184.26 [a]	87.88 [a]	12.23 [a]	3101.33 [a]	5827.39 [a]	43.54
Significance	***	**	***	***	**	ns
Interactions LOC × TRT	**	***	**	ns	*	ns
Year-II						
Source of Variation	**Tiller**	**Plant Height †**	**Spike Length †**	**Grain Yield ‡**	**Biomass Yield ‡**	**Thousand Kernel Weight**
Location (LOC)						
Banke	213.77 [b]	97.98 [a]	13.12 [b]	3728.75 [a]	8204.58 [a]	45.93 [a]
Morang	174.25 [c]	75.73 [c]	8.41 [c]	2479.17 [c]	4820.83 [b]	40.81 [b]
Rupandehi	317.56 [a]	87.28 [b]	13.71 [a]	3236.17 [b]	5201.25 [b]	41.33 [b]
Significance	***	***	***	***	***	***
Treatment (TRT)						
CP	208.71 [c]	84.53	10.28 [c]	2728.08 [b]	5750.00 [b]	42.34
IL	212.38 [c]	85.90	11.36 [b]	2787.50 [b]	5363.83 [b]	41.98
IH	214.71 [c]	86.53	12.23 [a]	2925.00 [b]	5861.08 [b]	41.24
CSAL	237.71 [bc]	86.65	12.01 [ab]	2918.67 [b]	5520.17 [b]	42.79
CSAM	265.67 [ab]	88.29	12.25 [a]	3815.25 [a]	6813.83 [a]	44.07
CSAH	272.00 [a]	90.08	12.34 [a]	3713.67 [a]	7144.42 [a]	43.71
Significance	***	ns	***	***	***	ns
Interactions LOC × TRT	**	***	***	***	***	ns

Significance codes: '***' for $p < 0.001$; '**' for $p < 0.01$; '*' for $p < 0.05$ and 'ns' for non-significant; † cm; ‡ kg ha^{-1}. Means followed by same lowercase letter are not significantly different.

3.2. Plant Height

A significant interaction effect of LOC × TRT on plant height was observed in both years of study (Table 2). The plant height varied within the range of 66.5–108 m in 2014/2015 and 70.4–105.7 m in 2015/2016. The highest plant height was gained in CSAH treatment in Banke for both years. Furthermore, each treatment resulted in an increased plant height compared to CP in all locations except in Morang for 2014/2015 and Rupandehi for 2015/2016, where IH and CSAL treatment had the lowest plant height, respectively (Figure 3).

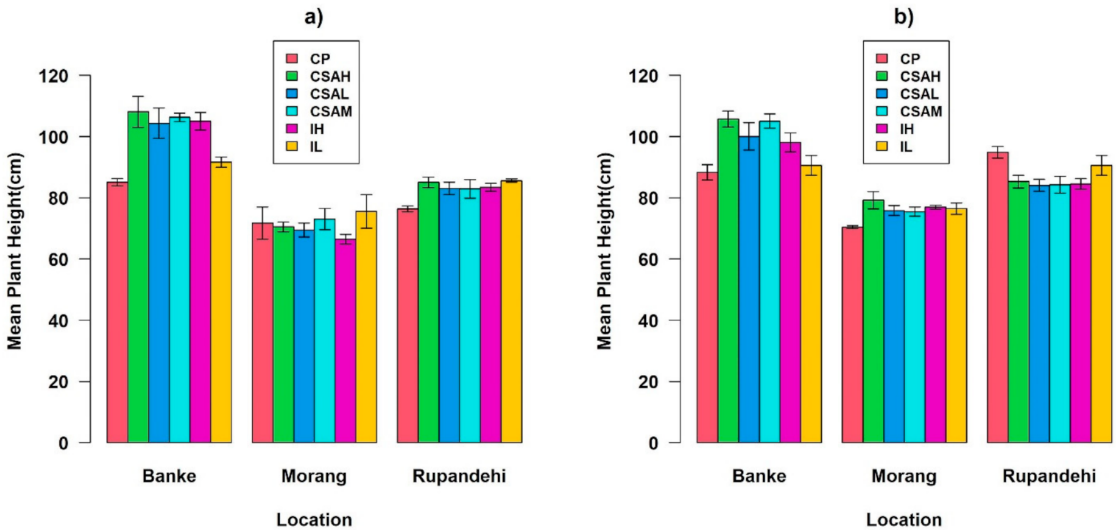

Figure 3. Plant height (mean ± SE) as affected by location × treatment interaction effect for wheat growing season in 2014/2015 (**a**) and 2015/2016 (**b**). Treatment included Controlled Practice (CP), Improved Low (IL), Improved High (IH), Climate Smart Agriculture Low (CSAL), Climate Smart Agriculture Medium (CSAM), and Climate Smart Agriculture High (CSAH).

3.3. Spike Length

A significant interaction effect of LOC × TRT on spike length was observed in 2014/2015 and 2015/2016 (Table 2). The spike length varied from 7.65 to 14.48 cm in 2014/2015 and from 7.25 to 15.13 cm in 2015/2016. The highest spike length was observed in CSAH treatment in Banke district for both years. Furthermore, each treatment resulted in an increased spike length compared to CP at specific locations except in Rupandehi district for 2015/2016, where only IL, IH and CSAH treatments had higher spike length compared to CP (Figure 4).

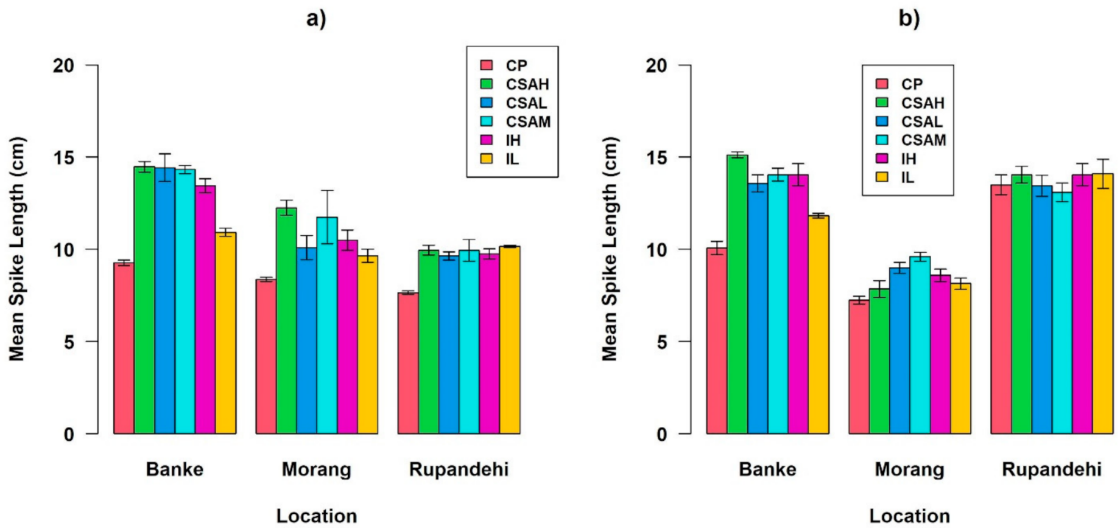

Figure 4. Length of spike (mean ± SE) as affected by location × treatment interaction effect for wheat growing season in 2014/2015 (**a**) and 2015/2016 (**b**). Treatment included Controlled Practice (CP), Improved Low (IL), Improved High (IH), Climate Smart Agriculture Low (CSAL), Climate Smart Agriculture Medium (CSAM), and Climate Smart Agriculture High (CSAH).

3.4. Grain Yield

There was a significant effect of TRT on grain yield in 2014/2015 (Table 2). There was a 5.5, 55.4, 54.2, 52.6, and 27.6% higher grain yield from CSAM, CSAL, CSAH, IH, and IL treatments, respectively, compared to the CP treatment. Grain yield was also varied significantly across three locations (LOC). The highest yield was obtained in Banke (3772.35 kg ha^{-1}) followed by Rupandehi (2504.47 kg ha^{-1}) and Morang (2224.94 kg ha^{-1}) (Table 2).

In 2015/2016, there was a significant interaction effect of LOC × TRT on grain yield (Table 2). The grain yield ranged from 1850 kg ha^{-1} in CP in Morang to 4757.5 kg ha^{-1} in CSAH in Banke districts. The results from a specific location in 2015/16 showed that CSAH treatment outperformed other treatments with the highest grain yield in Banke and Rupandehi, while CSAM resulted in the highest grain yield in Morang district (Figure 5).

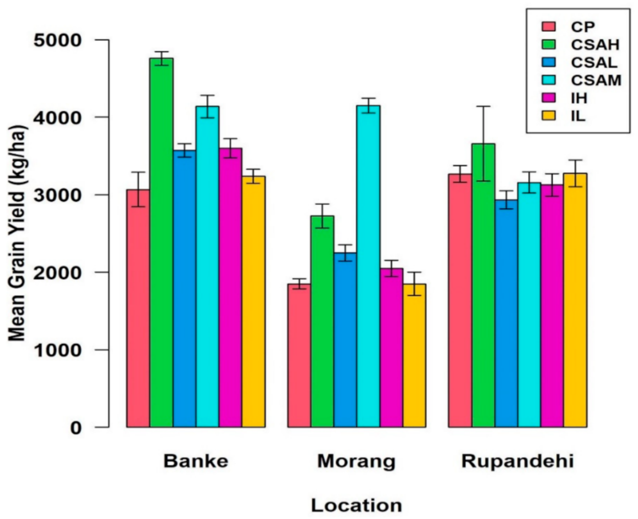

Figure 5. Wheat grain yield (mean ± SE) as affected by location × treatment interaction effect for wheat growing season in 2015/16. Treatment included Controlled Practice (CP), Improved Low (IL), Improved High (IH), Climate Smart Agriculture Low (CSAL), Climate Smart Agriculture Medium (CSAM), and Climate Smart Agriculture High (CSAH).

3.5. Biomass Yield

A significant interaction effect of LOC × TRT on biomass yield was observed in 2014/2015 and in 2015/2016 (Table 2). The biomass yield ranged from 2959 to 9359 kg ha^{-1} in 2014/2015 and from 3825 to 11,225 kg ha^{-1} in 2015/2016. The highest biomass yield was obtained in CSAH treatment in Banke district for both years (Figure 6). Furthermore, each treatment resulted in an increased biomass yield compared to CP in Banke and Morang districts for both years. However, biomass yield across treatments was always lower than the farmers' practice in Rupandehi district (Figure 6).

3.6. Thousand Kernel Weight

There was a significant effect of LOC on thousand kernel weight (TKW) while no effect of treatment was observed in 2014/2015 (Table 2). Wheat grains obtained from Morang had a higher TKW compared to that obtained from Banke and Rupandehi districts. Similarly, there was a significant effect of LOC on TKW in 2015/2016 (Table 2). The highest TKW was obtained from CSAM followed by CSAH treatment. Across locations, TKW was higher in Banke compared to other locations.

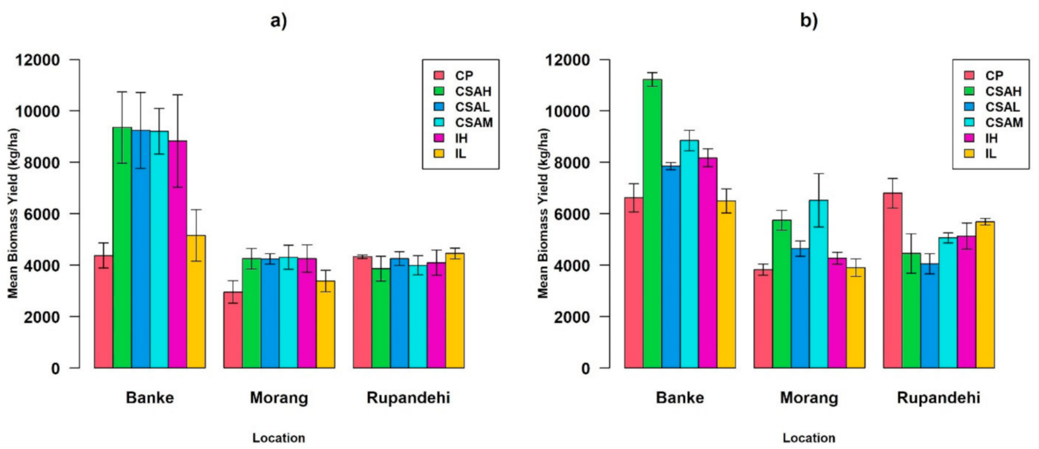

Figure 6. Biomass yield (mean ± SE) as affected by location × treatment interaction effect for wheat growing season 2014/2015 (**a**) and 2015/2016 (**b**). Treatment included Controlled Practice (CP), Improved Low (IL), Improved High (IH), Climate Smart Agriculture Low (CSAL), Climate Smart Agriculture Medium (CSAM), and Climate Smart Agriculture High (CSAH).

3.7. Correlation among Observed Parameters

Grain yield was significantly correlated with plant height, spike length, biomass yield, and TKW (Table 3). The positive correlation of spike length with grain yield ($r^2 = 0.46$, $p < 0.001$) suggests that the length of spike can regulate the number of grains that can be held in a spike and hence the grain yield. However, grain yield was not correlated with tiller count. All other parameters recorded were significantly correlated with each other with the exception of correlation between TKW and tiller.

Table 3. Correlation coefficient (r) between different yield-attributing parameters recorded during the study.

	Tiller	Plant Height	Spike Length	Grain Yield	Biomass Yield	TKW
Tiller	–					
Plant Height	0.39 ***	–				
Spike Length	0.67 ***	0.73 ***	–			
Grain Yield	0.41	0.67 ***	0.68 ***	–		
Biomass Yield	0.17 *	0.74 ***	0.48 ***	0.72 ***	–	
TKW	0.07	0.62 ***	0.38 ***	0.60 ***	0.66 ***	–

Significance codes: '***' for $p < 0.001$ and '*' for $p < 0.05$. TKW stands for thousand kernel weight.

4. Discussion

In the current study, yield and yield-attributing parameters were found to be affected by the treatments and locations. The plant population was higher in other treatments over CP, which might be the result of intervention of one or more climate smart practices. Bartaula et al. [40] and Khalid et al. [26] reported that effective tiller per square meter was higher for zero tillage practice compared to conventional tillage. The higher plant height was observed in the treatments including climate smart interventions compared to CP. The improvement in plant height in climate-smart intervened treatments might be due to the increased efficiency of N use facilitated by timely application of N and moisture retention. Similar results were obtained in study conducted by Malghani et al. [41]. However, Thapa et al. [42] reported a non-significant effect of tillage and residue management on plant height of wheat.

Difference in TKW was observed as an effect of location and treatment. Several previous studies have shown that TKW is affected by the location, tillage, and N management practices [40,43]. Rieger et al. [43] found that no-till system resulted in lower TKW compared to conventional tillage. Thapa et al. [44] reported a significant difference in TKW with N management while no difference was observed among the tillage treatments

Grain yield was found to be improved with CSAH and CSAM treatments. The increased yield in CSAH and CSAM treatments over farmers practice might be attributed to the inclusion of no-till and residue retention systems [45,46]. Pittelkow et al. [47] have indicated that no-till practice can help achieve yield advantage over conventional tillage when it is coupled with crop residue management. Bahri et al. [22] reported that zero-till with residue retention resulted in the highest water use efficiency in wheat, which might also explain the yield differences among treatments in our study. Furthermore, the synergistic effect of green manure incorporation in rice might be attributed to the increased wheat yield in CSAH [48]. Previous studies have reported a decline in yield with no-till compared to conventional tilled plots [43,47]. The contrasting results observed in the current experiment might be due to the synergistic effect of other treatments used in combination with no-till. No-till coupled with crop rotation and residue retention have been found to conserve soil resources by reducing wind and water erosion [49] as well as improvement in soil quality via enhanced biological activity in soil, water use efficiency, and soil physical properties [50,51].

Biomass yield was higher when the treatment had a combination of conventional tillage and residue retention, among others. Thapa et al. [44] also found similar results where no-till plots had lower biomass yield compared to conventional till plots, however, a significantly higher biomass yield resulted in mulched plots in comparison to the non-mulched wheat.

In general, number of tillers, plant height and grain yield were comparable or higher in CSAM and CSAH relative to CSAL treatments. The CSAM and CSAH treatments' plots received a precise N rate using decision support tools (LCC and Greenseeker, respectively), which led to a reduced N application rate. This suggested that the use of decision support tools can potentially lead to savings in fertilizer cost without compromising the grain yield compared to the current recommended N rate. These results are in accordance with results from another field experiment in Banke district [52], where they found savings of up to 50 kg N ha^{-1} from N application based on optical sensor. Crop sensors are emerging tools for efficient N management globally and a thorough evaluation of such tools in Nepalese content can be beneficial to optimize N from agronomic, economic, and environmental aspects.

5. Conclusions

The current study revealed that the incorporation of climate smart intervention is beneficial in improving the wheat grain yield and yield-attributing components in Nepal. Across all locations, CSAH and CSAM proved to be the most efficient interventions as compared to other climate smart practices as both treatments consistently gave better performance for various yield-attributing traits like plant population, spike length, thousand kernel weight, and overall grain yield irrespective to location, climate and soil type. Furthermore, the result indicates that no till cultivation of wheat with rice-residue retained and precisely applied N rates, with or without green manuring, can improve the grain yield of wheat in a rice-wheat cropping system. Since there was an effect of environment in the current study, further evaluation of these different climate smart interventions across diverse locations is required to have a better understanding and encourage farmers to adopt these practices. Future studies on analyzing the economic aspects of adaptation of climate smart interventions can be important for farmer-scale recommendation of the technologies.

Supplementary Materials: The following are available online at https://www.mdpi.com/2225-1154/9/2/19/s1, Table S1: Soil test results of research sites.

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